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**THESIS**

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QUANTIFYING THE VALUE OF RECONNAISSANCE  
USING LANCHESTERIAN TYPE EQUATIONS

By

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March 1994

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**QUANTIFYING THE VALUE OF RECONNAISSANCE  
USING LANCHESTERIAN TYPE EQUATIONS**

by

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Captain, United States Army  
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Submitted in partial fulfillment  
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**MASTER OF SCIENCE IN OPERATIONS RESEARCH**

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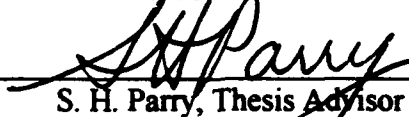
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## ABSTRACT

This paper presents a method to quantify the value of reconnaissance for both direct and indirect fire weapons for the defense-in-sector battle scenario. The Lanchester area fire model and the Helmbold equations were modified to allow the lethality of the defending blue force to be increased as they gained more combat intelligence about the attacking red force, thus modeling intelligence as a true combat multiplier. By adjustments made to parameters in the model, the lethality of blue direct and indirect fire weapons could be adjusted based on the quantity and quality of their intelligence assets. With information from a computer database, and the COMAN model, maximum likelihood attrition rate estimates were calculated for both red and blue forces for ten heavy defensive battles conducted at the Army's National Training Center. In each battle, the red force attrition rate was fitted to a curve which represented a percentage of blue's full potential, represented here by the square law. Using this model in a combat simulation, and with some preliminary work with comparable systems, one could implement a change in blue's intelligence assets and then provide a quantitative measure of the effect that this had on the outcome of a battle.

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## EXECUTIVE SUMMARY

Due to its nature, reconnaissance has been evaluated primarily in a qualitative sense in the past. However, the ability to quantify this value and directly apply this information to modeling our warfighting capabilities has not been accomplished. Without this measure, it is impossible for models to accurately weigh the costs and benefits of reconnaissance systems.

For a unit in battle, it is common knowledge that the proper use of intelligence assets will serve as a combat multiplier. However, current models generally have shortcomings when portraying the quantitative effect that they have on the outcome of the battle. The methods presented in this paper effectively translate *enemy information* into a weighting factor on the unit's ability to attrite the enemy. Two models are needed: an area fire model which is used for the indirect fire weapons such as artillery and mortars, and an aimed fire model which is used for the direct fire weapons such as tanks and missiles.

Lanchester equations have long been used to model force-on-force attrition under many different scenarios. Also the problem of assessing the value of the information gained from reconnaissance is not new. However, most models are somewhat tentative and incomplete by their own admission. The attempt in this thesis is to construct and validate a model which can be implemented throughout the modeling community.

Two different equations are used to model area and aimed fire. However, the intuitive argument behind both equations is the same; blue's weapons become more lethal as the blue force gains more knowledge about red's course of action (COA). In the area fire model, as blue gains information regarding red's COA, they can effectively reduce the area covered by their indirect fire weapons and improve specification of their target lists. A decrease in the area occupied by the red force results in increased effectiveness throughout the fire support battlefield operating system and hence, an increase in the lethality of their indirect fire weapons. The Lanchester linear law is used to model this where the ratio of the lethal area of a round to the area of the target is used explicitly.

The ratio is continually updated until the close battle commences, at which time red's attrition rate from blue's indirect fire weapons becomes fixed.

In the aimed fire model, the rate at which blue attrits red is bounded above and below by the square and the linear law Lanchester equations, respectively. As blue's perception of red's course of action approaches the ground truth, the blue force becomes more lethal. This is accomplished through use of a modified Helmbold equation by increasing what is known as the Weiss parameter. Similarly, if blue's perception deviates from ground truth, the Weiss parameter decreases. Ultimately the battle will be fought with blue attriting the red force at some percentage of their total potential, represented by the square law.

A positive correlation was shown to exist between the performance evaluation of a unit's use of intelligence information on the battlefield and the rate at which it attrited the red force. This was done with a nonparametric rank correlation technique and the use a subjective scoring of the performance narrative along with the attrition rate estimate obtained from the actual National Training Center defensive battle data. This result further emphasizes the need for combat simulations to quantitatively account for the use of intelligence assets in their attrition models.

The aimed fire model was applied to ten defensive battles conducted at the Army's National Training Center (NTC), and a Weiss parameter value was obtained for each of the battles, which represents a quantitative measure of effectiveness for each battle.

Further research was discussed to include extending the model to the heterogeneous case. Also discussed was the use of these attrition models in the Future Theater Level Model (FTLM). The FTLM is a new simulation which is in need of an attrition model, and would be well served to exploit the strengths of the equations presented in this study.

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# I. INTRODUCTION

The goal of this thesis is to provide an analytical tool which quantitatively demonstrates the value of reconnaissance as a function of time. Additionally, this thesis will provide recommendations for further development of the model.

Considering the current emphasis on reduced spending and the downsizing of the military forces, it is necessary to focus on the most efficient use of our resources. Additionally the transition from the Cold War Era into a multi-polar world and a contingency force military structure demands that we maximize the combat effectiveness of our military forces. Now, more than ever it is critical to gain quick victory by rapidly massing fires instead of troops and engaging the enemy at the maximum effective range of our weapon systems. The information collected through reconnaissance missions helps us to accomplish this and continues to serve as an important combat multiplier for commanders.

For a unit in battle, it is common knowledge that the proper use of intelligence assets will serve as a combat multiplier. However, current models generally have had shortcomings when portraying the quantitative effect they have on the outcome of the battle. The methods presented in this paper effectively translate *enemy information* into a weighting factor on the unit's ability to attrite the enemy. Two models are needed: an area fire model which is used for the indirect fire weapons such as artillery and mortars, and an aimed fire model which is used for the direct fire weapons such as tanks and missiles. Once the model development has been discussed, the data which were gathered from ten battles conducted at the Army's National Training Center (NTC) will be described. Finally, these data are used to show how the units can be rated according to the magnitude of what is referred to as the Weiss parameter. This is a number which can be interpreted as the percentage of the unit's full potential to attrite the enemy.

Lanchester equations have long been used to model force-on-force attrition under many different scenarios [Refs. 1 and 2]. Also, the problem of assessing the value of the information gained from reconnaissance is not new [Refs. 3 and 4]. However, most

models are somewhat tentative and incomplete by their own admission. The attempt in this thesis is to construct and validate a model which can be implemented throughout the modeling community.

Due to its nature, reconnaissance has been evaluated primarily in a qualitative sense in the past. However, the ability to quantify this value and directly apply this information to modeling our warfighting capabilities has not been fully realized. Without this measure, it is impossible for models to accurately weigh the costs and benefits of reconnaissance systems.

In Chapter II, some of the traditional Lanchester equations are presented and then modified to reflect the use of intelligence as a combat multiplier. These are presented along with intuitive arguments as to why these modifications satisfy military judgment. Also discussed are the basic battlefield scenarios for the area and aimed fire models for use throughout the thesis.

Chapter III describes the data which were acquired from the Army Research Institute, at the Presidio of Monterey (ARI-POM), from 10 defensive battles fought at the National Training Center (NTC) at Fort Irwin, California. Also described are the selection criteria used in choosing these ten battles. These data forms include numerous database tables. Additionally the form and structure of the database provided by the ARI-POM, and how it was manipulated and cleaned for the purpose of this thesis are discussed. These data forms include numerous database tables as well as the narrative take home package (THP). The final discussion in this chapter describes how this information was reorganized into a consolidated data table which will be used and expanded in the analysis.

The analysis of the data is presented in Chapter IV, where the method and calculations which produced the COMAN model maximum likelihood estimate (MLE) of various attrition rates from the NTC data are described. Also the battles are ranked according to two measures of effectiveness (MOEs), and a positive correlation is shown to exist between how well a unit uses its intelligence assets and the rate at which it

actually attritted the red force. Finally a method is described which quantitatively measures the effectiveness of the use of reconnaissance and the processing of intelligence information using the NTC battle data with the modified Helmbold equations.

The final chapter contains the conclusions of the study and several suggestions for further research. The discussion outlines possible extensions of the models, opportunities to employ these results and a summary of the ongoing research.

## II. THE LANCHESTER MODELS

In this chapter some of the traditional Lanchester equations are presented and then modified to reflect the use of intelligence as a combat multiplier. These are presented along with intuitive arguments as to why these modifications make sense. The resulting equations will be applied in Chapter IV, *Analysis*. Also discussed are the basic battlefield scenarios for the area and aimed fire models for use throughout the thesis.

### A. GENERAL

The traditional Lanchester equations can be written as the

$$\text{linear law:} \quad \frac{dR}{dt} = -\alpha_B R B, \quad (1)$$

and the

$$\text{square law:} \quad \frac{dR}{dt} = -\beta_B B, \quad (2)$$

where  $R$  and  $B$  are the respective red and blue force sizes,  $\alpha_B$  represents blue's ability to attrit red with area fire, and  $\beta_B$  represents blue's ability to attrit red with aimed fire.

Now it can be shown that the square law is closely related to the linear law. In fact, the two attrition rate coefficients can be written in terms of one another. Consider representing the square law attrition rate coefficient as

$$\beta_B = r_B \times P_{ssk}, \quad (3)$$

where  $r_B$  is the firing rate of blue's weapons and  $P_{ssk}$  is the probability of a kill per round fired. In the area fire case, assuming  $r_B$  to be a constant, the expected number of kills per round can be thought of as

$$P_{ssk} = A_L \times \frac{R}{a_{tgt}} = \frac{A_L}{a_{tgt}} \times R, \quad (4)$$



where  $A_L$  is the lethal area of one round,  $R$  is the number of red targets, and  $a_{tgt}$  is the area occupied by the red force. In words it can be written as

$$P_{ssk} = (\text{lethal area of round}) \times (\text{target density}). \quad (5)$$

Equations (2), (3), and (4) above provide the following expression for the attrition rate [Ref. 5]:

$$\frac{dR}{dt} = r_B \frac{A_L}{a_{tgt}} RB. \quad (6)$$

Equation (6) is another way of expressing the linear law since it depends on  $R$ . The initial statement regarding the similarities in the two attrition rate coefficients can easily be shown since

$$\alpha_B = r_B \frac{A_L}{a_{tgt}}, \quad (7)$$

and

$$\beta_B = r_B \frac{A_L}{a_{tgt}} R = \alpha_B R. \quad (8)$$

## B. AREA FIRE

The Lanchester Linear Law is the foundation for the equation used here. The idea is to reward the blue force for the information it has gained by increasing the rate at which it attrits the red force. The more intelligence blue gathers regarding red's probable courses of action (COA), the more lethal blue's area fire weapons become. This increase is determined by the ratio  $\frac{A_L}{a_{tgt}}$ .

Consider the following scenario which is depicted in Figure 1. The blue force defends against red who will attack along some combination of five available avenues of approach (AOA), each of which has similar physical characteristics and is five square kilometers in size. At time,  $t_0$ , the blue force has no information regarding red's COA.

Therefore he assesses the use of each AOA to be equally likely during the attack. This means the blue indirect fire assets are divided equally to cover each of the five AOAs. Blue's reconnaissance objective is to determine how much of red's strength will come down each AOA, as well as the force composition. Suppose for now that  $r_B$  is a constant, and use the initial conditions shown in Table 1.

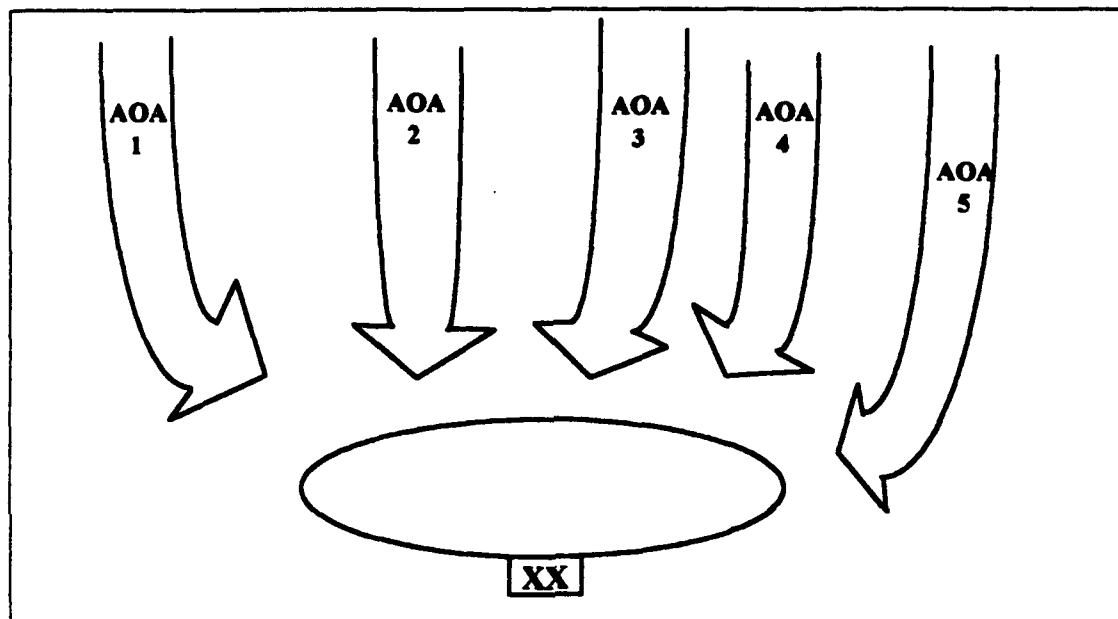


Figure 1. First Area Fire Scenario

TABLE 1. EXAMPLE PARAMETERS FOR THE AREA FIRE MODEL

Parameter Value	Units
$R = 1250$	elements
$B = 24$	area fire weapons
$A_L = 0.00785$	square kilometers
$a_{tgt} = 25$	square kilometers
$r_B = 4$	rounds per weapon per minute

This yields the following attrition rate for the red forces at time  $t_0$ ,

$$\frac{dR}{dt} = -4 \left( \frac{0.00785}{25} \right) (1250)(24) = -37.7 \frac{\text{kills}}{\text{minute}}. \quad (9)$$

In this simple example we can extract the values for the attrition rate coefficients as

$$\alpha_B = 4 \left( \frac{0.00785}{25} \right) = 0.00126, \quad (10)$$

and

$$\beta_B = 4 \left( \frac{0.00785}{25} \right) (1250) = 1.57. \quad (11)$$

Now suppose the blue force has gained some information regarding red's current activity and location. Based on this information he reevaluates the enemy's probable COA. Suppose further that blue determines that the force will use only AOAs 1, 2 and 3 as shown in Figure 2. It follows that he will allocate his indirect fire assets according to these same proportions. Blue has in effect reduced the area of his target. This will result in a higher attrition rate against red for blue's area fire weapons, which is calculated as

$$\frac{dR}{dt} = -4 \left( \frac{0.00785}{15} \right) (1250)(24) = -62.8 \frac{\text{kills}}{\text{minute}}. \quad (12)$$

Blue will continue to update the probable enemy COAs and reallocate his area fire assets. Provided that blue's intelligence was accurate and that his analysis was correct, he will ultimately attrit the red forces with area fire at a higher rate than if he had not used his reconnaissance assets. The graph in Figure 3 below shows the effect of reducing  $a_{gr}$ , while all other parameters are held constant. Each line represents a change in the total

area occupied by the red forces. The attrition rate of the blue forces is held constant at the arbitrary value of 3 percent.

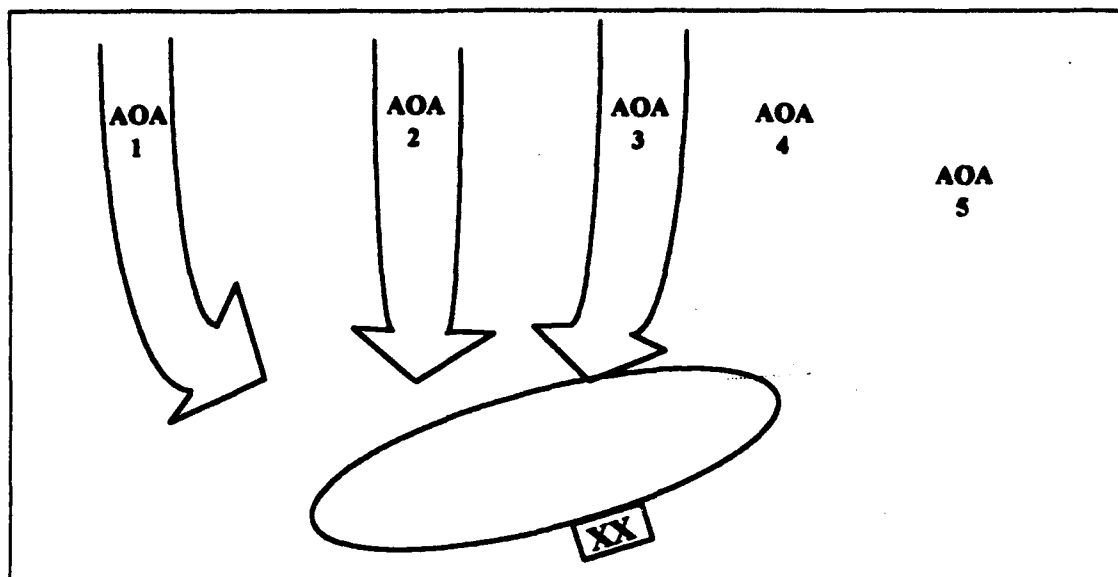


Figure 2. Second Area Fire Scenario

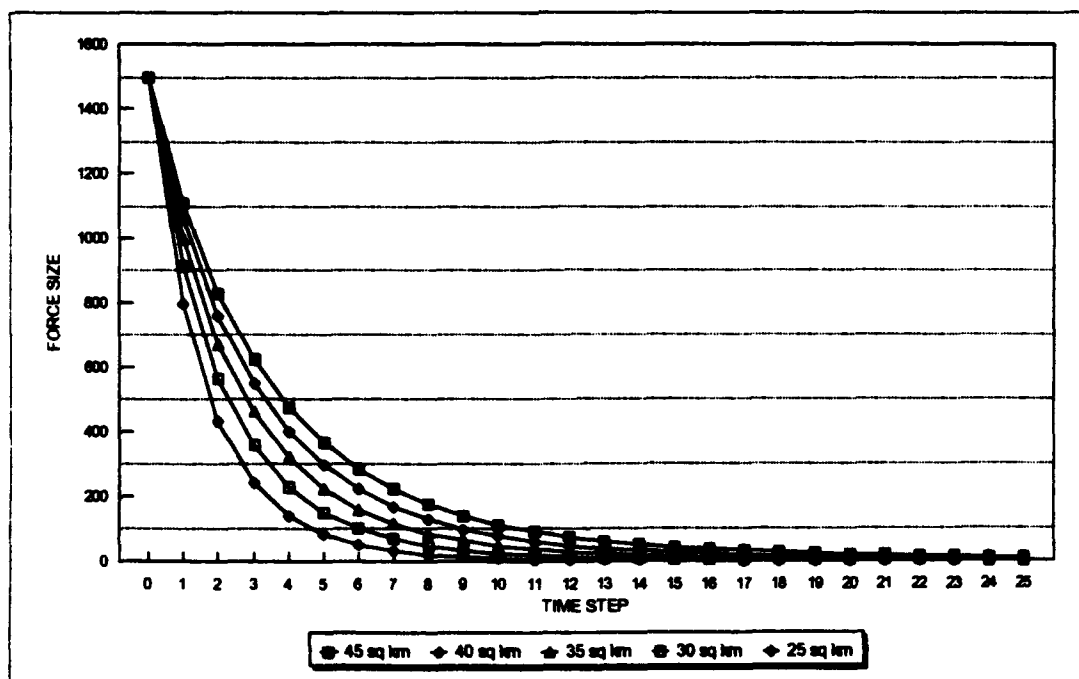


Figure 3. Effect Of  $a_{attr}$  On Enemy Force Size

### C. AIMED FIRE

Lanchester's square law is the basis for the equation used in this section, but here it is not related to the *area* of the AOAs, but instead, the *number* of AOAs. However, the key aspect of this model is similar to the area model in that the blue force gains information through reconnaissance efforts and applies this knowledge to increase his combat effectiveness. The aimed fire model does require a slightly different approach. The Helmbold modification of Lanchester's square law serves as a starting point to model the situation. The Helmbold equation is written as

$$\frac{dR}{dt} = -\beta_B \left( \frac{R}{B} \right)^{1-\omega} B, \quad (13)$$

where  $\beta_B$  is the rate at which blue attrits red using aimed fire, and  $\omega$  is referred to as the Weiss parameter. Here, as before, both B and R are force strengths as a function of time.

Traditionally Helmbold's equations have been used to account for inefficiencies of scale for a larger force when the initial force sizes are grossly unequal [Ref. 5]. In Equation (13) above, the force ratio term is less than one, and the term  $\left( \frac{R}{B} \right)^{1-\omega}$  can be interpreted as a weighting factor on the red attrition rate. Helmbold argued that a force which greatly outnumbered its opponents could not bring all its weapons to bear against the enemy. Note that when the Weiss parameter,  $\omega$ , is equal to one, the Helmbold equation is the same as the square law. However, for values less than one, only a percentage of the square law attrition rate is applied. In effect, the intelligence contribution *offsets* the Weiss parameter.

The analogy here is that since the blue force is defending in such a manner that it can not bring direct fire from all its weapons to bear on the attacking red forces, the inefficiencies are the same as those described in the traditional Helmbold scenario. In other words, some of blue's direct fire weapons will not be used effectively in attriting red. Recall that the square law assumes that every blue firer can engage every red target, and this can be modeled with the Weiss parameter equal to one. It is necessary to make

one change to the traditional Helmbold equation, since the force ratio term must be less than one. Thus, for the case of blue defending against a larger red force, the equation now is written as

$$\frac{dR}{dt} = -\beta_B \left( \frac{B}{R} \right)^{1-\omega} B. \quad (14)$$

Note the consistencies with the original Helmbold equation. When  $\omega = 1$  it reduces to the square law, and for values  $0 \leq \omega < 1$ , a percentage of the full attrition rate results.

It can be argued that there are other factors which can weigh heavily in determining success on the battlefield, (such as command and control, morale, timeliness and execution of the order) and therefore may have some influence on the magnitude of  $\omega$ . However, in this study it is hypothesized that the differences in  $\omega$  are primarily due to levels of intelligence. In Chapter IV Equation (14) will be used for curve fitting actual attrition data from NTC battles. In this curve fitting, even though  $\omega = 1$  represents blue's highest aspirations, it is understood that this level of attrition is virtually impossible to achieve for two reasons. First, in order to have a Weiss parameter equal to one, the unit would have to have perfect intelligence, as well as perfect command and control, and perfect execution, etc. Secondly, the square law assumes that *all* blue weapons are able to mass fires on all red targets.

Also, the lower bound of  $\omega = 0$  can only be considered a *soft* bound. Two battles are fit to a curve with negative Weiss parameter values. Even though the classical interpretation of Equation (13) does not hold for these cases, the result still serves as a relative measure, used to compare the attrition rates in these NTC battles.

Next consider how information gained by blue regarding red's COA can be used to increase the lethality of its own direct fire weapons. Consider the following simplified scenario. Blue defends with 50 tanks covering five AOAs. Initially, blue has no information about how red will allocate his forces along these AOAs. With no knowledge, and assuming all AOAs have identical physical characteristics, he will

allocate 20% of his direct fire assets to cover each of the five AOAs. If the battle were to be fought under these conditions, blue would attrit red at a rate very close to the lower bound for this situation.

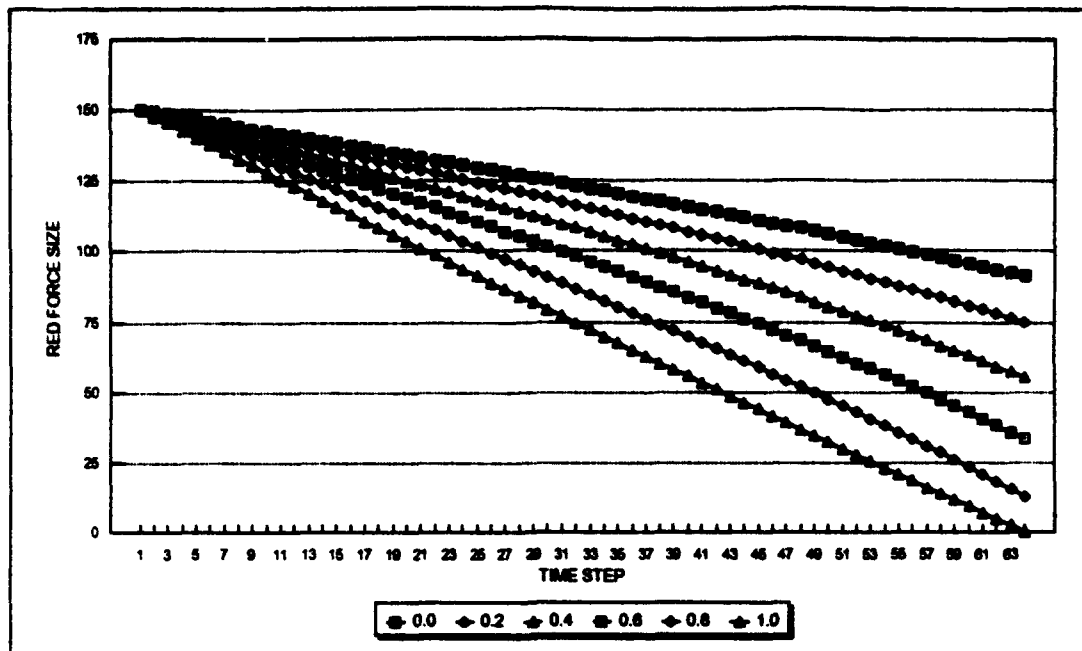
Next suppose that blue has acquired some useful information from a recon element and has adequate time to reposition his direct fire weapons so that larger portions are bringing fire to bear on the attacking red forces. Emphasis is placed on the *timeliness* of the information that blue gathers. This suggests that there is some key time period in the battle at which  $\omega$  will be fixed, say for example 2-6 hours before the close battle begins. This time varies depending on the actual characteristics of the battle. The blue commander can also adapt to delayed information by the method in which he employs his reserve and how long he has had to prepare supplementary fighting positions.

If blue has perfect information regarding his opponent, and has had adequate time to prepare his defense, then he would use his direct fire weapons in the most effective manner possible. In this case the magnitude of the Weiss parameter would increase. Consider the initial conditions shown in Table 2.

**TABLE 2. EXAMPLE PARAMETER VALUES FOR DIRECT FIRE MODEL**

Parameter Value	Units
$R = 150$	vehicles
$B = 50$	direct fire weapons
$\beta_B = 0.05$	red attrition rate from blue direct fire weapons
0.08	fixed attrition rate for blue

Figure 4 shows the effects of changing the Weiss parameter on the attrition rate of the opponent.



**Figure 4. Effects On Red's Attrition Rate For Varying Weiss Parameter Values.**



### **III. DATA**

Data were acquired from the Army Research Institute, at the Presidio of Monterey (ARI-POM), from 10 defensive battles fought at the National Training Center (NTC) at Fort Irwin, California. This section describes the selection criteria used in choosing these ten battles. These database forms include numerous database tables. Additionally the form and structure of the data provided by the ARI-POM, and how it was manipulated and cleaned for the purpose of this thesis are discussed. These data forms include numerous database tables as well as the narrative take home package (THP). The final discussion describes how this information was reorganized into a consolidated data table which will be used and expanded in Chapter IV, *Analysis*.

#### **A. SOURCES**

##### **1. The National Training Center (NTC)**

The mission of the NTC is to provide highly realistic and intensified combined arms and services training for battalion task forces based in the continental United States and squadrons in a mid- to high-intensity combat environment. Since 1981 heavy brigades, with or without light elements, have been going to the NTC to train for 14 days and nights on tactical missions with force-on-force Multiple Integrated Laser Engagement System (MILES) engagements against an opposing force (OPFOR) employing Warsaw Pact tactics. The NTC schedules twelve rotations each year. On the average, a rotation consists of nine force-on-force and four live-fire exercises for each of the two battalion task forces.

The NTC's 1,000 square miles is considered to be some of the harshest terrain in the U.S. Simulated combat situations constantly arise demanding rapid assessments, timely decision making, and effective employment of artillery, air defense, engineers, aviation, and combat service support units. No other training presents in combination the scope, scale, and intensity of effort that is captured at the NTC. Its instrumented,

one-of-a-kind battlefield provides instant feedback and heightens learning at all levels.  
[Ref. 6]

## **2. The Army Research Institute, Presidio of Monterey (ARI-POM)**

The ARI-POM is designated to be the Army's repository for data collected at the NTC as well as the other Combat Training Centers; the Combat Maneuver Training Center (CMTC) and the Joint Readiness Training Center (JRTC). The ARI-POM Archive is one of the prime sources of Army unit performance data in existence. Initial development of the CTC Archive began in 1985 with a limited set of NTC materials. During the spring of 1990, the CTC Archive was expanded to include a wider variety of paper, video, audio, and digitized data types from the JRTC and the CMTC. [Ref. 7]

## **B. BATTLE SELECTION CRITERIA**

The goal of the battle selection criteria was to represent the population of rotations at NTC through a sampling of NTC battles with similar characteristics. In order to accomplish this, many battles were considered in order to find those with similar characteristics. Listed below are the selection criteria for the NTC battles.

### **1. Digitized Data**

Not all data from the NTC rotations on file at ARI-POM have been digitized. However, digitized data were essential for this thesis, in order to rapidly and accurately manipulate the large volume of data required for analysis, and to exploit the power of the personal computer along with several software packages.

### **2. Mission: Defense in Sector**

This type of mission is most appropriate for this thesis. Gaining enemy intelligence is most critical in a defense mission. In an offensive mission, one usually has a good understanding of the adversary, his location, equipment, etc.

### **3. Unit Type: Armor, Mechanized or Cavalry**

These unit types were chosen to add consistency to the data. Heavy units tend to defend using similar tactics and have nearly the same equipment, differing only in the

proportion of tanks and APCs. In fact, at the battalion task force level, elements can be nearly identical, and serve well for the purposes of this thesis.

#### **4. Similar Terrain**

Although it was not possible to select battles fought on exactly the same terrain, the preference was for the battles occurring within a certain area of NTC which offers similar major terrain features, such as defensible terrain and similar avenues of approach, to add consistency to the data.

#### **5. Recent NTC Rotation**

With the changes in equipment, tactics and with the evolving state of NTC itself, only rotations which occurred within the past five years were candidates for selection.

### **C. TAKE HOME PACKAGES (THPs)**

#### **1. Description**

This narrative feedback to units emphasizes a review of unit performance. For rotations after November 1987, the reporting was within the framework of the battlefield operating systems (BOS). THPs from earlier rotations contained the same information, but were organized by mission [Ref. 8]. The documents, written by the officer and non-commissioned officer (NCO) Observer/Controllers (O/Cs), are primarily narrative with some battle statistics gathered from the Core Instrumentation Subsystem (CIS).

#### **2. Contents/Data Elements**

The THPs available on floppy disk contained four main sections; Section I - General Summary; Section II - Mission Statements and Commander's Intent; Section III - BOS/Lessons Learned; Section IV - Statistical Analysis [Ref. 8]. Within each section, the mission segments were discussed as they occurred chronologically. Each document is typically 200-250 pages in length.

Sections of particular interest for this thesis are the O/C comments on the Intelligence and Fire Support BOSs for the particular defense-in-sector battles, and the

consolidated comments made at the end of the rotation regarding unit trends for these same two BOSs.

## D. DATA TABLES

### 1. The Player Status Initialization Table (PSIT)

The PSIT describes the list of vehicles at the beginning of the defense-in-sector mission. It includes all red and blue players as well as O/Cs [Ref. 8]. The original table included nine fields; however, only the three listed in Table 3 were used. The PSIT was used primarily to identify the side and weapon type, given a particular Logical Player Number (LPN). Figure 5 shows a few typical lines from a PSIT as received from the ARI-POM.

**TABLE 3. FIELDS USED FROM PSIT**

FIELD NAME	FIELD DESCRIPTION
LPN	Logical player number, (unique to each vehicle, all sides)
SIDE	Either B(lue), R(ed) or O(bserver)
PTYPE	Player type code, which is cross referenced in another table

pid	lpn	side	lnat	lactive	ltype	long	ltrack	lstat
101	30000	0	1	0	0	TOC	1	1
102	30001	0	1	0	0	TOC	1	1
103	30002	0	1	0	0	TOC	1	1
106	30003	0	1	0	0	TOC	1	1

**Figure 5. An Extract From The PSIT Printout**

### 2. The Player/Vehicle/Weapon Code Table (PVWT)

The PVWT defines a unique code for each weapon system on the battlefield. The code allows correlation of MILES codes, vehicle types, and weapons. The PVWT is static, and does not change from rotation to rotation [Ref. 8]. The fields used from this

table are listed in Table 4. Figure 6 shows the first few lines from the PVWT printout from the ARI-POM.

**TABLE 4. FIELDS USED FROM PVWT**

FIELD NAME	FIELD DESCRIPTION
PTYPE	Player type code
WEAPON	Description of unique weapon system

side	lptype	lvehicle	liles	lweapon	lanno
0	0	Undefined	0	Unknown	0
1	1	M20 A1/A3 Tank	12	100mm main gun	1
2	2	Abrams	15	120mm main gun	2
3	3	M20 A1/A3 Tank	27	Coax	3
4	4	M20 A1/A3 Tank	28	100mm (miss)	4
5	5	M20 A1/A3 Tank	29	Coax (miss)	5
6	6	APC	30	100mm Machine Gun	6
7	7	APC	31	100mm (miss)	7
8	8	APC	32	100mm	8

**Figure 6. An Extract From The PVWT Printout**

### 3. The Pairing Events Table (PET)

The PET is considered by ARI-POM to be the heart of the NTC research database. This is the table that describes the direct fire assessments on a play-by-play basis. The pairing table maintains a time-ordered record of legitimate pairing events [Ref. 8]. In a few cases the PET provided information regarding the firer, but not in enough pairings to be of use in this thesis. The fields used from the PET are listed in Table 5. Figure 7 shows some sample data extracted from the PET.

**TABLE 5. FIELDS USED FROM THE PET**

FIELD NAME	FIELD DESCRIPTION
TIME	Date and time of pairing
TLPN	Logical player number of the target
RESULT	N(ear miss), H(it) or K(ill)



time	lpid	lpen	lside	linst	lotype	lorg	lstat
00:00:00	00	00	00	00	00	00	00
00:00:01	00	00	00	00	00	00	00
00:00:02	00	00	00	00	00	00	00
00:00:03	00	00	00	00	00	00	00
00:00:04	00	00	00	00	00	00	00
00:00:05	00	00	00	00	00	00	00
00:00:06	00	00	00	00	00	00	00
00:00:07	00	00	00	00	00	00	00
00:00:08	00	00	00	00	00	00	00
00:00:09	00	00	00	00	00	00	00
00:00:10	00	00	00	00	00	00	00
00:00:11	00	00	00	00	00	00	00
00:00:12	00	00	00	00	00	00	00
00:00:13	00	00	00	00	00	00	00
00:00:14	00	00	00	00	00	00	00
00:00:15	00	00	00	00	00	00	00
00:00:16	00	00	00	00	00	00	00
00:00:17	00	00	00	00	00	00	00
00:00:18	00	00	00	00	00	00	00
00:00:19	00	00	00	00	00	00	00
00:00:20	00	00	00	00	00	00	00
00:00:21	00	00	00	00	00	00	00
00:00:22	00	00	00	00	00	00	00
00:00:23	00	00	00	00	00	00	00
00:00:24	00	00	00	00	00	00	00
00:00:25	00	00	00	00	00	00	00
00:00:26	00	00	00	00	00	00	00
00:00:27	00	00	00	00	00	00	00
00:00:28	00	00	00	00	00	00	00
00:00:29	00	00	00	00	00	00	00
00:00:30	00	00	00	00	00	00	00
00:00:31	00	00	00	00	00	00	00
00:00:32	00	00	00	00	00	00	00
00:00:33	00	00	00	00	00	00	00
00:00:34	00	00	00	00	00	00	00
00:00:35	00	00	00	00	00	00	00
00:00:36	00	00	00	00	00	00	00
00:00:37	00	00	00	00	00	00	00
00:00:38	00	00	00	00	00	00	00
00:00:39	00	00	00	00	00	00	00
00:00:40	00	00	00	00	00	00	00
00:00:41	00	00	00	00	00	00	00
00:00:42	00	00	00	00	00	00	00
00:00:43	00	00	00	00	00	00	00
00:00:44	00	00	00	00	00	00	00
00:00:45	00	00	00	00	00	00	00
00:00:46	00	00	00	00	00	00	00
00:00:47	00	00	00	00	00	00	00
00:00:48	00	00	00	00	00	00	00
00:00:49	00	00	00	00	00	00	00
00:00:50	00	00	00	00	00	00	00
00:00:51	00	00	00	00	00	00	00
00:00:52	00	00	00	00	00	00	00
00:00:53	00	00	00	00	00	00	00
00:00:54	00	00	00	00	00	00	00
00:00:55	00	00	00	00	00	00	00
00:00:56	00	00	00	00	00	00	00
00:00:57	00	00	00	00	00	00	00
00:00:58	00	00	00	00	00	00	00
00:00:59	00	00	00	00	00	00	00
00:01:00	00	00	00	00	00	00	00

Figure 8. An Extract From The PSUT Printout

##### 5. The Indirect Fire Casualty Table (IFCT)

The IFCT portrays indirect fire casualties similarly to PET for the direct fire casualties. However, none of the ten battles considered had a complete IFCT. No other tabled data in the ARI-POM NTC database offer a complete picture of the indirect fire battle.

#### E. REORGANIZATION OF DATA

Each of the ten battles that were selected according to the criteria listed above had their own set of tables. These tables were combined into one summarizing table which provided all the data necessary to estimate the attrition rates for each battle. The ARI-POM tables were combined using a three dimensional spreadsheet which provided easy cross-referencing. The Consolidated Data Table (CDT) is described in Table 7. A few rows of the CDT are shown as an example in Figure 9.

TABLE 7. FIELDS FROM THE CDT

FIELD NAME	FIELD DESCRIPTION
TIME	Time of pairing
TLPN	Logical player number of the target
RESULT	N(ear miss), H(it), or K(ill)
GAME TIME	Time origin set to time of first shot of battle
KILL	Running count of the total kills
VEHICLE TYPE	Describes the side, (B or R), and vehicle, (Tank, APC or Other)

TIME	Target LNP	RESULT	Game Time	KILL	VEHICLE TYPE
06:35:00	N/A	N/A	00:00:00	N/A	N/A
06:36:00	148	K	00:01:00	1	R-OTHER
06:06:20	369	K	00:00:32	2	B-TANK
06:46:58	326	K	00:11:58	3	B-APC
07:13:13	35	K	00:30:13	4	R-APC
07:13:16	66	K	00:30:16	5	R-APC
07:14:16	42	K	00:39:16	6	R-APC
07:17:56	370	K	00:42:56	7	B-TANK

**Figure 9. An Extract From The CDT Printout**

The CDT contains all the information required to calculate the Combat Analysis Model (COMAN) maximum likelihood estimates (MLE) of attrition. These fields and the method in which the CDT was expanded to produce these estimates are explained in Chapter IV.



## IV. ANALYSIS

This chapter describes the method and calculations which produced the COMAN model maximum likelihood estimate (MLE) of various attrition rates from the NTC data. The interested reader can find the mathematics behind the COMAN model briefly explained in reference 9; reference 10 contains the complete derivation and a more complete discussion of the model, and reference 11 provides some interesting applications of an extended COMAN model.

Also in this chapter, the battles are ranked according to two measures of effectiveness (MOEs), and a positive correlation is shown to exist between how well a unit uses its intelligence assets and their relative worth during the battle. Finally, a method is described which quantitatively measures the effectiveness of the use of reconnaissance and the processing of intelligence information using the NTC battle data with the modified Helmbold equations.

### A. COMAN MODEL MLE AND RELATIVE WORTH

#### 1. COMAN Model

##### a. Methodology

To estimate the direct fire attrition rates from the data obtained from the ARI-POM database, the Combat Analysis (COMAN) Model was used. The mathematical equation for the rate at which blue attrits red using direct fire weapons is

$$\hat{\beta}_B = \frac{C_T^R}{\sum_{k=1}^K B_{k-1}(t_k - t_{k-1})} \quad (15)$$

where  $C_T^R$  is the number of red casualties at time  $T$ , (the end of the battle);  $K$  is the total number of casualties to both sides;  $B_{k-1}$  is the number of blue firers after the  $(k-1)$ st casualty; and  $(t_k - t_{k-1})$  is the time in minutes between the  $k$ th and the  $(k-1)$ st casualties. Similarly the rate at which red attrits blue can be written as

$$\hat{\beta}_R = \frac{C_T^B}{\sum_{k=1}^K R_{k-1}(t_k - t_{k-1})} \quad (16)$$

The units of these equations are

$$\hat{\beta}_B = \frac{\text{Total number of Red casualties}}{\text{Total number of Blue firer minutes}} \quad (17)$$

and

$$\hat{\beta}_R = \frac{\text{Total number of Blue casualties}}{\text{Total number of Red firer minutes}} \quad (18)$$

In order to use a spreadsheet to calculate  $\hat{\beta}_B$  and  $\hat{\beta}_R$ , the following columns were added to the CDT described in Chapter III.

**TABLE 8. COMBINED DATA TABLE DESCRIPTION**

FIELD NAME	FIELD DESCRIPTION
COUNT B-APC	The total number of blue APCs still operational
COUNT B-TANK	The total number of blue tanks still operational
COUNT R-APC	The total number of red APCs still operational
COUNT R-TANK	The total number of red tanks still operational
ALL BLUE	The total number of blue APCs and tanks still operational
ALL RED	The total number of red APCs and tanks still operational
T <sub>k</sub>	Number of minutes until the kth kill
B <sub>k</sub>	Number of blue firers at the time of the kth kill
R <sub>k</sub>	Number of red firers at the time of the kth kill
T(k)-T(k-1)	Number of minutes between the kth and k-1st kill
B <sub>k</sub> [T(k)-T(k-1)]	Number of blue firer minutes between the kth and k-1st kill
R <sub>k</sub> [T(k)-T(k-1)]	Number of red firer minutes between the kth and k-1st kill

An extract from the CDT showing the new columns is shown in Figure 10. A sample calculation of the COMAN MLE of the red's attrition rate for both tanks and APCs illustrates the procedure. Cell I1 is the initial number of tanks and APCs for red. The value in cell I52 is the number of red tanks and APCs at the end of the battle. The difference in these two cells is the total number of red casualties. The value in cell K53 is the sum of cells K2 through K52, and represents the total number of blue firer minutes. For this example, according to Equation (17), the COMAN MLE for the attrition rate of red tanks and APCs is,  $\frac{153-132}{9,376} = 0.00224$ . There are six different attrition rate estimates which can be calculated in this manner; red tanks and APCs combined, red tanks, red APCs, blue tanks and APCs combined, blue tanks, and blue APCs. The consolidated data table (CDT) for each battle is contained in Appendix A.

	A	B	C	D	E	F	G	H	I	J	K	L
	COUNT B-APC	COUNT B-TANK	COUNT R-APC	COUNT R-TANK	ALL BLUE	ALL RED	Tk	Bk	Rk	T(K)-T(K-1)	Bk[T(K)- T(K-1)]	Rk[T(K)- T(K-1)]
1	47	30	98	55	77	153	0	77	153	N/A	N/A	N/A
2	47	30	98	55	77	153	1	77	153	1	77	153
3	47	29	98	55	76	153	9	76	153	8	570	1,148
4	46	29	98	55	75	153	12	75	153	4	263	536
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
50	43	25	82	51	65	133	105	68	133	1	54	106
51	43	25	81	51	68	132	107	68	132	2	102	198
52	43	25	81	51	68	132	130	68	132	23	1,557	3,023
53											9,376	18,452

Figure 10. Example Of The Additional Fields In The CDT.

**b. Rank Using the COMAN MLE**

There are numerous possible methods for ranking the ten battles using the data available in the ARI-POM database; the highest attrition rate, the fewest friendly casualties, or the most enemy casualties, are just a few. If the enemy attrition rate is used

to rank the battles, an erroneous conclusion may result. For example, Table 9 shows that Armor battle #4 has the highest attrition rate against red, with the COMAN MLE being 0.00611. Armor battle #5 has a relatively low MLE of 0.00123. However, in battle #5, there were ten more red casualties and three fewer blue casualties than in battle #4. The COMAN MLE is a function of both red casualties, *and* blue firer-minutes. In this example, battle #5 lasted over 8 1/2 hours longer than did battle #4. Using enemy attrition rate shows only that in battle #5 the casualties occurred at a slower rate. If it were possible to select battles of nearly equal length, this MOE would be adequate. However, that is not a viable choice for this analysis, since large differences exists for the battle lengths.

## 2. Relative Worth

One MOE which is often used, and serves our purpose better, is commonly referred to as *relative worth*, defined as the ratio of the attrition rate of the blue force to the attrition rate of the red force. A relative worth greater than one means that blue is attriting red faster than red is attriting blue. Most importantly, this MOE is not a function of the length of the battle. The last column in Table 9, relative worth, is defined as

$$\frac{\frac{\text{TOTAL RED CASUALTIES}}{\text{BLUE FIRER MINUTES}}}{\frac{\text{TOTAL BLUE CASUALTIES}}{\text{RED FIRER MINUTES}}} = \frac{\text{RED ATTRITION ESTIMATE}}{\text{BLUE ATTRITION ESTIMATE}} = \text{RELATIVE WORTH.} \quad (19)$$

Table 9 shows the actual figures for this MOE, as well as other battle summary statistics, ranked according to relative worth.

**TABLE 9. BATTLE SUMMARY FIGURES**

BATTLE	LENGTH IN MINUTES	RED CASUALTIES	BLUE CASUALTIES	RED FIREB	BLUE FIREB	RED ATTRITION RATE	BLUE ATTRITION RATE	RELATIVE WORTH
3	90	35	8	196	74	0.00584	0.0005	11.680
5	638	55	18	190	80	0.00123	0.00016	7.688
9	711	19	11	198	53	0.00058	0.00008	7.250
10	440	26	16	198	54	0.00123	0.00019	6.474
4	117	45	21	202	75	0.00811	0.001	6.110
1	130	21	9	153	77	0.0024	0.00049	4.898
7	132	31	18	196	79	0.00385	0.00079	4.873
8	572	23	18	190	83	0.00056	0.00017	3.294
2	208	22	14	153	84	0.00214	0.00077	2.779
6	235	5	7	196	58	0.00041	0.00015	2.733

## **B. UNIT PERFORMANCE**

### **1. General**

One of the key postulates in this thesis is that the better a unit utilizes the Intelligence BOS, the more effective they will be in attriting the enemy. Thus far, the COMAN MLE has been used as an indicator of the blue force's ability to attrite the enemy. Also available for analysis is the narrative THP which describes in detail how the unit performed in each of the BOSs according the O/Cs at the NTC. The attempt here is to devise a scoring system which allows the ten battles to be ranked from the best to worst according to their THP evaluation of the Intelligence BOS. This ranking can be compared to the ranking using the COMAN MLE and the correlation can be measured. If a positive correlation exists between these two ranking methods, then it would reinforce the original postulate that intelligence gathering, analysis, and dissemination impacts on a unit's ability to kill the enemy.

### **2. Methodology and Ranking**

Besides the ARI-POM mission database tables, the other source of data for the battles is the Take Home Packet. Included in this narrative, written primarily by the

officer and non-commissioned officer O/Cs at the NTC, is the unit's performance evaluation regarding each of the battlefield operating systems. Since there does not currently exist any actual *performance scores* for a unit by either the NTC or the ARI-POM, a scoring system was devised which was used to rank the battles according to the unit's performance evaluation, concentrating solely on the Intelligence BOS. The attempt here is to assign a *score* to each unit regarding its efficient use of reconnaissance assets within the Intelligence BOS. In order to obtain a value for this measure based on the written evaluation, it is more appropriate to score each paragraph in the narrative as opposed to each sentence, since ideally, the paragraph contains a complete thought and cannot be taken out of context. The main difficulty was devising a scoring system which would produce consistent results from judge to judge. There is inherently a large amount of subjectivity to scoring a written paragraph. Therefore a scoring algorithm was devised to remove as much of the subjectivity as possible, without losing information, or even worse, biasing the scores of the judges. Each paragraph within the intelligence section of the written evaluation was placed into one of five categories by each judge.

- **Highly Positive:** a paragraph which contains high praise for the units performance regarding important aspects of the Intelligence BOS. An example of a highly positive paragraph would contain sentences like, *"The template developed by the S2 did an excellent job of identifying MCs and avenues of approach."*
- **Positive:** a paragraph which praises the units performance, but to a lesser degree than the above category, or it may contain a caveat. An example of a positive paragraph may contain phrases like, *"Recon and counter-recon operations were generally, but not always executed in a timely manner."*
- **Neutral:** if the paragraph does not address any pertinent topics, or the positive comments are equally balanced with the negative comments.
- **Negative:** a paragraph which contains criticisms regarding the Intelligence BOS. An example would be, *"Light discipline of the recon platoon could use some improvement."*

- **Highly Negative:** a paragraph which contains heavy criticism, regarding important aspects of the Intelligence BOS. The paragraph may be one or two very critical sentences, or it may contain numerous sentences which criticize to a slightly lesser degree. An example of a very critical sentence contained in a highly negative paragraph would be, *"During both night operations, the platoon was unable to detect the mounted recon before it penetrated the task force zone."*

These five categories are shown in Figure 11, along with the symbols used by the judges and the associated values used for the scoring.

	Highly Positive	Positive	Neutral	Negative	Highly Negative
Judge's Rating	++	+	O	-	--
Associated Score	3	1	0	-1	-3

**Figure 11. Scoring System For Narrative Evaluation**

Appendix C contains additional instructions to the judge to ensure he understands the purpose and definitions of the categories. These instructions include guidelines, precautions, and a flow chart which explains the process step by step. This was done to ensure that all the judges were assessing the same MOE. An example of how a typical battle was scored is shown in Appendix D. Three separate judges were asked to score all ten battles using this system, and produced remarkably consistent results. Table 8 shows their results as well as the ranking according to the battle's relative worth (Equation 19).

**TABLE 10. RANKING OF BATTLES ACCORDING TO THE THP<sub>s</sub> AND RELATIVE WORTH**

BATTLE	RANK				
	JUDGE 1	JUDGE 2	JUDGE 3	AVERAGE	REL. WORTH
1	10	8.5	8	8.83	6
2	6	5	6.5	5.83	9
3	1	1	1	1.00	1
4	6	10	10	8.67	5
5	6	6	4	5.33	2
6	8	8.5	6.5	7.67	10
7	9	7	9	8.33	7
8	2	3	3	2.67	8
9	4	4	2	3.33	3
10	3	2	5	3.33	4

The Spearman's coefficient of rank correlation, which measures the degree of correspondence between rankings instead of between actual variate values, was used to test these two ranked lists. The recommended formula [Ref. 12] for calculating this coefficient, because the ranked lists contain ties, is written as

$$R = \frac{\sum_{i=1}^n (X_i - \bar{X})(Y_i - \bar{Y})}{\left[ \sum_{i=1}^n (X_i - \bar{X})^2 \sum_{i=1}^n (Y_i - \bar{Y})^2 \right]^{1/2}}, \quad (20)$$

where  $X_i$  and  $Y_i$  are the  $i$ th elements in the two lists, and  $n$  is the number of elements in each list. The data from the last two columns in Table 10 above, produces the Spearman's coefficient,  $R = 0.49$ . It is encouraging that  $R$  is positive, yet due to all the other factors which contribute to unit success, it is not extremely large. This correlation between the performance of the unit on the battlefield and their level of proficiency in



using their reconnaissance and intelligence assets shows that intelligence is, in fact, a combat multiplier and should be accounted for in modeling combat attrition.

### **C. APPLYING THE LANCHESTERIAN TYPE EQUATIONS TO THE NTC BATTLES**

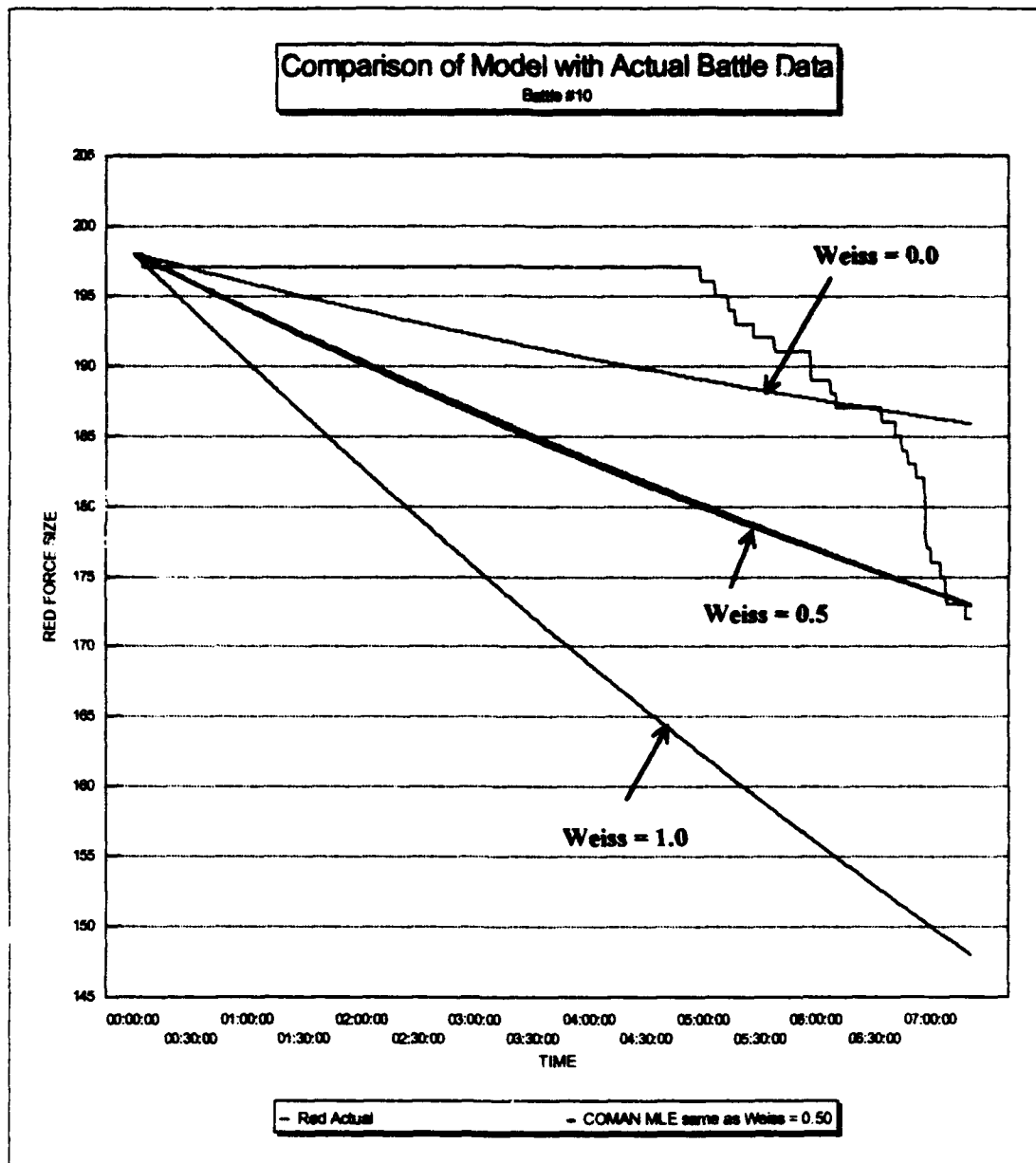
The COMAN model provides an estimate of the average attrition rate of the red force for each of the ten NTC battles. A modified Helmbold equation having one parameter which can be varied to model different levels of intelligence is also used. In Figure 12, the modified Helmbold equation is plotted with three different Weiss parameter values for Battle #10. It is relatively straightforward to see that in this battle, the red attrition rate could be represented using the modified Helmbold equation with a Weiss parameter of approximately 0.50.

As discussed in Chapter II, there are many factors which influence whether or not a unit is successful in battle. Therefore it is possible for a unit to have perfect intelligence regarding its enemy and attrit him at a rate less than the perfect square law due to command and control, morale, execution, etc. This phenomenon may be present in Battle #10, shown in Figure 12, which is the battle where the COMAN MLE was fit to the curve with the highest parameter value,  $\omega = 0.5$ , and yet is still quite far from the square law.

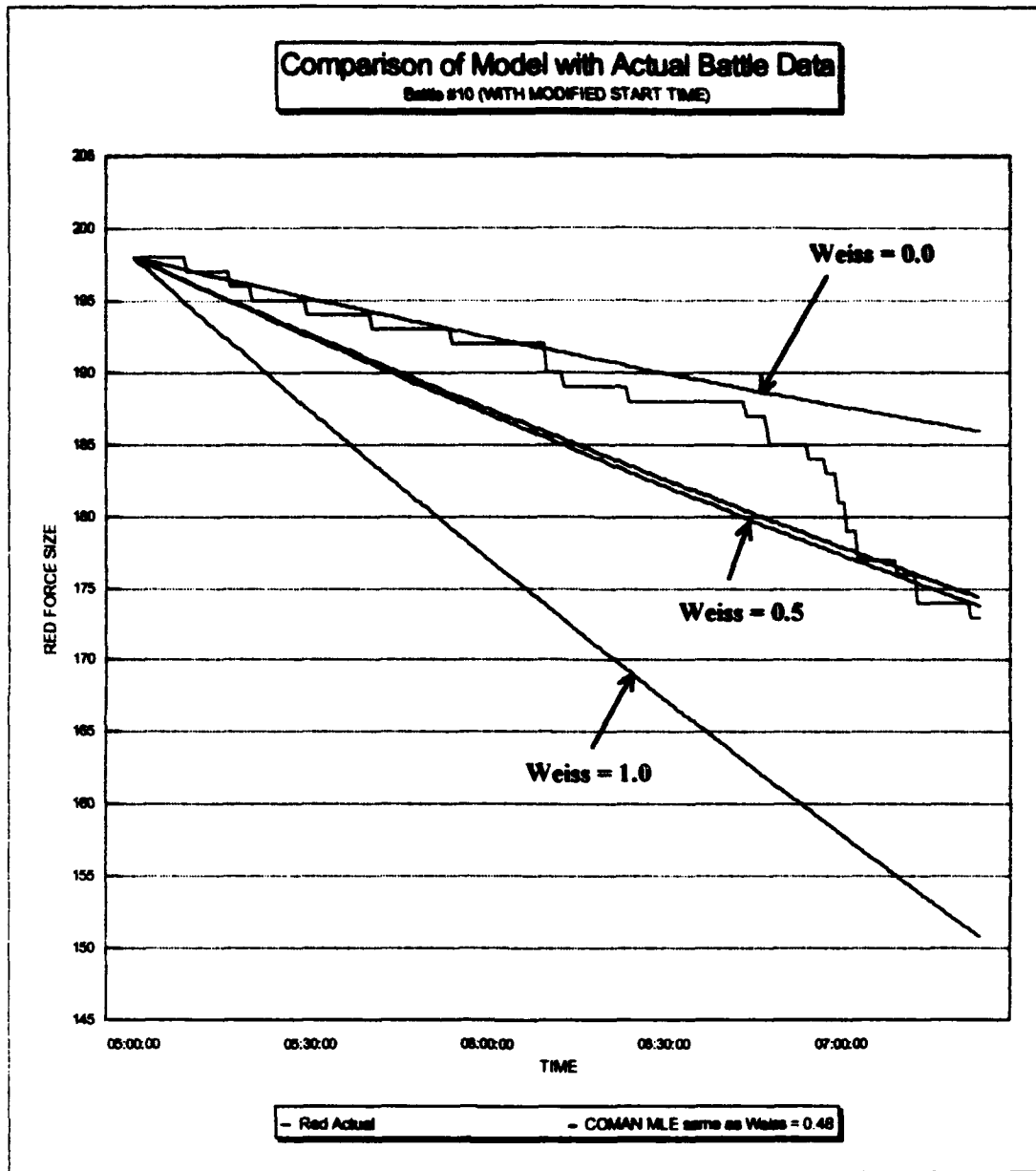
Examining Battle #10 more closely raises an interesting point. It appears that it would make a great difference in the Weiss parameter value if the start of the battle was chosen differently. In fact the COMAN estimate of  $\beta_B$  more than doubles if the start of the battle is moved forward about five hours. However, Figure 13 shows that in this case the Weiss parameter fit of 0.48 is nearly the same. What has occurred in this example is the smaller blue force size has offset the effect of the increased attrition coefficient. Figure 14 shows a plot of the blue force size over the course of the entire battle. Notice that blue suffered about 10 percent casualties, (nearly half of its total casualties for the battle) during the first five hours of the fighting, while red lost only about 2 percent. The decrease in the force size,  $B$ , and necessarily the force ratio component,  $\frac{B}{R}$ , offset the

increase in the magnitude of the attrition coefficient,  $\beta_B$ , resulting in effectively no change in the modified Helmbold equation, which was introduced before

$$\frac{dR}{dt} = -\beta_B \left( \frac{B}{R} \right)^{1-\omega} B. \quad (21)$$



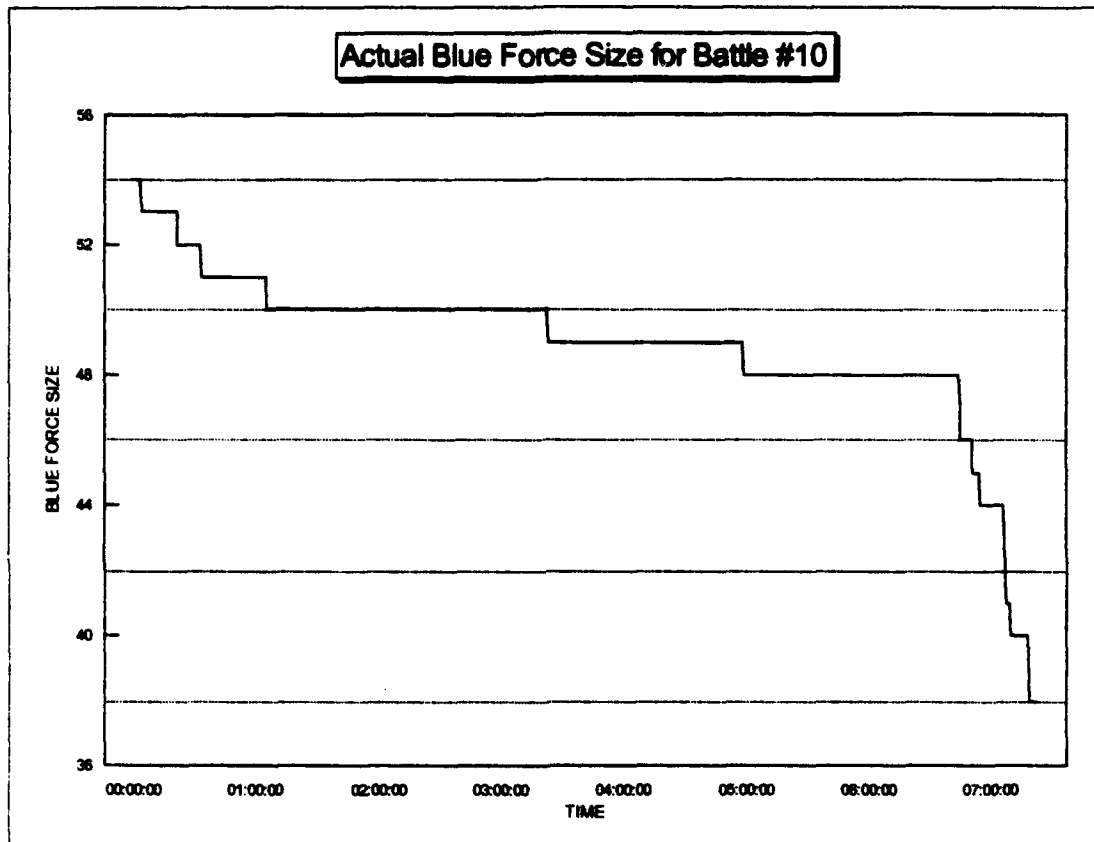
**Figure 12. Coman Estimate And Modified Helmbold Equations Of Battle #10**



**Figure 13. Battle #10 With The Modified Start Time**

Battle #10 depicts realistically what often occurs in battle. As an attacking force approaches its opponent, the weapons with the greatest effective range are employed first. In this case, blue suffered substantial casualties in the long range battle, but did much better in the subsequent fighting at closer ranges. The battlefield can essentially be

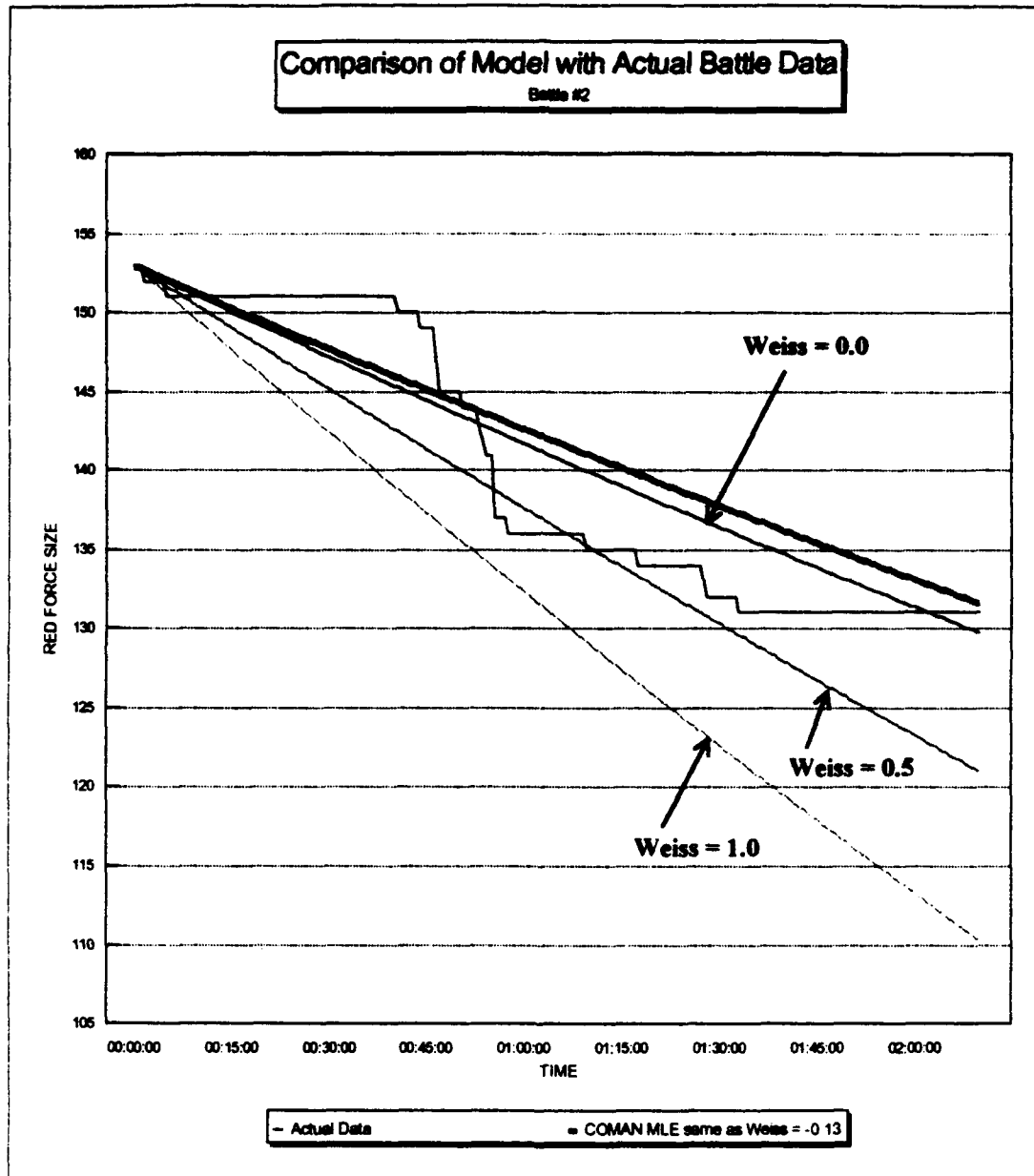
divided into range bands which correspond to the weapons systems with various effective ranges. In fact, the original work conducted by Clark used this approach in calculating separate attrition estimates for each range band [Ref. 9]. However, the data available for this thesis did not provide the necessary information to incorporate this level of detail.



**Figure 14. Blue Force Size For Battle #10**

The lower bound of  $\omega = 0$  can only be considered a *soft* bound. Two of the NTC battles are fit to a curve with negative Weiss parameter values. Even though the classical interpretation of Helmbold's formulations do not hold for these cases, the result still serves as a relative measure used to compare the attrition rates in these NTC battles. Battle #2 is an example of a negative value, where the COMAN MLE is fit to the curve,

$\omega = -0.13$ , as shown in Figure 15. The graphs for all ten battles are contained in Appendix E. Table 11 shows all ten battle with the associated Weiss parameter value.



**Figure 15. Coman Estimate And Modified Helmbold Equations Of Battle #2**

**TABLE 11. WEISS PARAMETER FOR EACH NTC BATTLE**

BATTLE NUMBER	WEISS PARAMETER
1	-0.12
2	-0.13
3	0.27
4	0.31
5	0.16
6	0.45
7	0.26
8	0.20
9	0.49
10	0.50

## **V. CONCLUSIONS AND RECOMMENDED FURTHER RESEARCH**

### **A. CONCLUSIONS**

Through the modified Helmbold equations a quantitative measure of the value of reconnaissance can be obtained. Simulations can be run to determine the benefits of new systems, tactics and force structures. Prior to the close battle, periodic updates of  $\frac{A_L}{a_w}$  and  $\omega$  can be calculated. Through these updates, the lethality of the defending force's indirect and direct fire weapons increases accordingly. The parameters become fixed at some given point and the battle is fought.

### **B. RECOMMENDED FURTHER RESEARCH**

Possibly the most appropriate model for these equations is the Future Theater Level Model (FTLM), since it uniquely incorporates perceptions into the battle simulation. FTLM is a symbolic model characterized by its aggregated, stochastic, information-intensive, and dynamic nature [Ref. 13]. However, it may be necessary to restructure portions of the FTLM in order to simulate combat at the small unit level. Along with this is the requirement to incorporate the modified Helmbold equations presented in this study into the FTLM program code. The most natural approach would be to associate the magnitude of the Weiss parameter to how close the unit's perception regarding its enemy's COA is to the ground truth. Currently the Naval Postgraduate School is pursuing these topics for upcoming theses.

Further studies could help to better identify the upper and lower bounds on the Weiss parameter. As was stated, the upper bound lies somewhere below one, and it is possible using real data to obtain parameter values less than zero for the lower bound.

Additional research to obtain attrition rates for the heterogeneous case could also be very useful. However, the data required to facilitate this research may be difficult to obtain.

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## APPENDIX A

### CONSOLIDATED DATA TABLES (CDTS)

This appendix contains the CDTs for the ten defensive battles conducted at NTC. Below is a description of the column headings for quick reference.

Column	Heading	Description
1	Time	Time of the actual battle
2	Target LPN	Target logical player number, (unique to each vehicle)
3	Result	All the pairings in this table are (K)ills
4	Game Time	Duration of the battle
5	Kill	Running total of how many vehicles for both sides are killed
6	Vehicle Type	Denotes the side, (B)lue or (R)ed, and TANK, APC or OTHER
7	Count B-APC	Current number of mission capable blue APCs
8	Count B-Tank	Current number of mission capable blue tanks
9	Count R-APC	Current number of mission capable red APCs
10	Count R-Tank	Current number of mission capable red tanks
11	All Blue	Current number of mission capable blue vehicles
12	All Red	Current number of mission capable red vehicles
13	Tk	Game time (in minutes) of the <i>k</i> th kill
14	Bk	Total number of blue vehicles at the time of the <i>k</i> th kill
15	Rk	Total number of red vehicles at the time of the <i>k</i> th kill
16	T(k)-T(k-1)	Time (in minutes) between the (k-1)st and the <i>k</i> th kill
17	Bk[T(k)-T(k-1)]	Accumulated blue firer minutes between the (k-1)st and <i>k</i> th kill
18	Rk[T(k)-T(k-1)]	Accumulated red firer minutes between the (k-1)st and <i>k</i> th kill
19	Tk	Game time (in minutes) of the <i>k</i> th kill
20	Bk(APC)	Total number of blue APCs at the time of the <i>k</i> th kill
21	Rk(APC)	Total number of red APCs at the time of the <i>k</i> th kill
22	T(k)-T(k-1)	Time (in minutes) between the (k-1)st and the <i>k</i> th kill
23	Bk[T(k)-T(k-1)]	Accumulated blue APC firer minutes between the (k-1)st and <i>k</i> th kill
24	Rk[T(k)-T(k-1)]	Accumulated red APC firer minutes between the (k-1)st and <i>k</i> th kill
25	Tk	Game time (in minutes) of the <i>k</i> th kill
26	Bk(Tank)	Total number of blue tanks at the time of the <i>k</i> th kill
27	Rk(Tank)	Total number of red tanks at the time of the <i>k</i> th kill
28	T(k)-T(k-1)	Time (in minutes) between the (k-1)st and the <i>k</i> th kill
29	Bk[T(k)-T(k-1)]	Accumulated blue tank firer minutes between the (k-1)st and <i>k</i> th kill
30	Rk[T(k)-T(k-1)]	Accumulated red tank firer minutes between the (k-1)st and <i>k</i> th kill

At the bottom of each table is the total for columns 17, 18, 21, 22, 27, and 28, which represent the total firer minutes for the battle for the associated side and vehicle.

[illegible]







[illegible]







[illegible]



Time	Target LPI	Result	Game Time	Kill	VehicleType	Count B-APC	Count B-Tank	Count R-APC	Count R-Tank	All Blue	All Red	Tk	Bk	Rk	T(R)-T(R-1)	[[B(TD)-T(R-1)]]	[[R(TD)-T(R-1)]]	Tk	Bk	Rk	T(R)-T(R-1)	[[B(TD)-T(R-1)]]	[[R(TD)-T(R-1)]]	Tk	Bk	Rk	T(R)-T(R-1)	[[B(TD)-T(R-1)]]	[[R(TD)-T(R-1)]]	
01:21:30	300	K	00:00:00	1	R-OTHER	13	41	00	00	34	190	0	54	100	N/A	0	0	0	13	90	90	N/A	N/A	N/A	0	41	90	3	N/A	N/A
01:21:30	307	K	00:00:00	2	B-TANK	13	40	00	00	54	190	0	53	100	3	4	10	13	90	90	17	44	337	0	40	90	0	44	337	
01:21:30	40	K	00:00:00	3	R-OTHER	13	40	00	00	54	190	0	53	100	3	4	10	13	90	90	17	44	337	0	40	90	0	44	337	
01:21:30	40	K	00:00:00	4	B-TANK	13	40	00	00	54	190	0	53	100	3	4	10	13	90	90	17	44	337	0	40	90	0	44	337	
01:21:30	40	K	00:00:00	5	R-OTHER	13	40	00	00	54	190	0	53	100	3	4	10	13	90	90	17	44	337	0	40	90	0	44	337	
01:21:30	40	K	00:00:00	6	B-TANK	13	40	00	00	54	190	0	53	100	3	4	10	13	90	90	17	44	337	0	40	90	0	44	337	
01:21:30	40	K	00:00:00	7	R-OTHER	13	40	00	00	54	190	0	53	100	3	4	10	13	90	90	17	44	337	0	40	90	0	44	337	
01:21:30	40	K	00:00:00	8	B-TANK	13	40	00	00	54	190	0	53	100	3	4	10	13	90	90	17	44	337	0	40	90	0	44	337	
01:21:30	40	K	00:00:00	9	R-OTHER	13	40	00	00	54	190	0	53	100	3	4	10	13	90	90	17	44	337	0	40	90	0	44	337	
01:21:30	40	K	00:00:00	10	B-TANK	13	40	00	00	54	190	0	53	100	3	4	10	13	90	90	17	44	337	0	40	90	0	44	337	
01:21:30	40	K	00:00:00	11	R-OTHER	13	40	00	00	54	190	0	53	100	3	4	10	13	90	90	17	44	337	0	40	90	0	44	337	
01:21:30	40	K	00:00:00	12	B-TANK	13	40	00	00	54	190	0	53	100	3	4	10	13	90	90	17	44	337	0	40	90	0	44	337	
01:21:30	40	K	00:00:00	13	R-OTHER	13	40	00	00	54	190	0	53	100	3	4	10	13	90	90	17	44	337	0	40	90	0	44	337	
01:21:30	40	K	00:00:00	14	B-TANK	13	40	00	00	54	190	0	53	100	3	4	10	13	90	90	17	44	337	0	40	90	0	44	337	
01:21:30	40	K	00:00:00	15	R-OTHER	13	40	00	00	54	190	0	53	100	3	4	10	13	90	90	17	44	337	0	40	90	0	44	337	
01:21:30	40	K	00:00:00	16	B-TANK	13	40	00	00	54	190	0	53	100	3	4	10	13	90	90	17	44	337	0	40	90	0	44	337	
01:21:30	40	K	00:00:00	17	R-OTHER	13	40	00	00	54	190	0	53	100	3	4	10	13	90	90	17	44	337	0	40	90	0	44	337	
01:21:30	40	K	00:00:																											

## APPENDIX B

### NTC BATTLE DATA SUMMARY

#### BATTLES STATISTICS

	Battle									
	1	2	3	4	5	6	7	8	9	10
Relative Worth	4.59	2.77	11.66	6.1	7.87	2.69	4.85	3.34	7.21	6.5
Battle Length (hh:mm:ss)	2:09:41	2:10:19	1:29:41	1:57:10	10:37:19	3:54:38	2:12:09	9:36:21	11:50:36	7:21:56

#### BLUE BATTLE DATA SUMMARY

Battle	Unit Type	Initial Tanks	Initial APCs	Initial Total	Tank Firer Minutes	APC Firer Minutes	Total Firer Minutes	Tanks Lost	APCs Lost	Total Lost	Tank attrit rate*	APC attrit rate*	Total attrit rate*
1	Armor	30	47	77	3,553	5,822	9,375	5	4	9	0.00729	0.000345	0.000488
2	Armor	35	49	84	4,116	6,164	10,280	10	4	14	0.001513	0.000345	0.00077
3	Armor	36	38	74	3,008	3,365	6,373	7	1	8	0.000848	0.000129	0.000601
4	Armor	42	33	75	4,046	3,483	7,529	16	5	21	0.00146	0.0005	0.001002
5	Armor	32	48	80	16,272	29,834	46,106	14	4	18	0.000238	0.000071	0.000156
6	Cav	41	17	58	8,318	3,982	12,310	7	0	7	0.000305	0	0.000154
7	Mech	22	57	79	2,025	6,810	8,835	10	8	18	0.000868	0.000717	0.000793
8	Mech	29	54	83	15,294	29,534	44,828	8	10	18	0.000148	0.000188	0.000169
9	Mech	40	13	53	25,494	9,159	34,653	10	1	11	0.000145	0.000015	0.00008
10	Mech	41	13	54	16,033	5,311	21,344	15	1	16	0.000347	0.000024	0.000189

#### RED BATTLE DATA SUMMARY

Battle	Unit Type	Initial Tanks	Initial APCs	Initial Total	Tank Firer Minutes	APC Firer Minutes	Total Firer Minutes	Tanks Lost	APCs Lost	Total Lost	Tank attrit rate*	APC attrit rate*	Total attrit rate*
1	MRR	55	98	153	6,857	11,595	18,452	4	17	21	0.001126	0.00292	0.00224
2	MRR	56	97	153	6,609	11,580	18,189	9	13	22	0.002186	0.002109	0.00214
3	MRR	98	98	196	8,255	7,727	15,982	11	24	35	0.004041	0.007428	0.00584
4	MRR	101	101	202	10,959	10,008	20,967	16	29	45	0.003954	0.008614	0.00611
5	MRR	95	95	190	58,944	56,156	115,100	16	39	55	0.001015	0.001341	0.001228
6	MRR	98	98	196	22,969	22,542	45,511	1	4	5	0.000124	0.001002	0.000414
7	MRR	98	98	196	11,527	11,164	22,691	14	17	31	0.006913	0.002937	0.003848
8	MRR	95	95	190	54,173	53,206	107,379	9	14	23	0.00059	0.000542	0.000564
9	MRR	99	99	198	69,153	68,786	137,939	8	11	19	0.000314	0.00131	0.000577
10	MRR	99	99	198	43,189	42,269	85,458	10	16	26	0.000623	0.003013	0.001228

\* Attrition rate values are the COMAN MLE attrition rate estimate.

## APPENDIX C

### INSTRUCTIONS TO SCORER OF THP NARRATIVE

Shown below are the instructions provided to the judges who scored the THPs.

1. Use the flowchart on the following page as a guideline.

2. Example of what might be considered a *very positive comment* within a paragraph:

"The template developed by the S2 did an excellent job of identifying MCs and avenues of approach."

3. Example of what might be considered a *very negative comment* within a paragraph:

"However the avenues of approach analysis were not continuous throughout the sector nor were the MCs through the Furlong and the Whale identified. The TF was aware of the dismounted avenues of approach, but these were not adequately analyzed."

4. Look for key words and phrases that indicate the correct subject matter.

(i.e. IPB, DST, R&S, Terrain Analysis, Tracking of enemy recon elements, Identification of enemy avenues of approach or MCs or COAs, etc.)

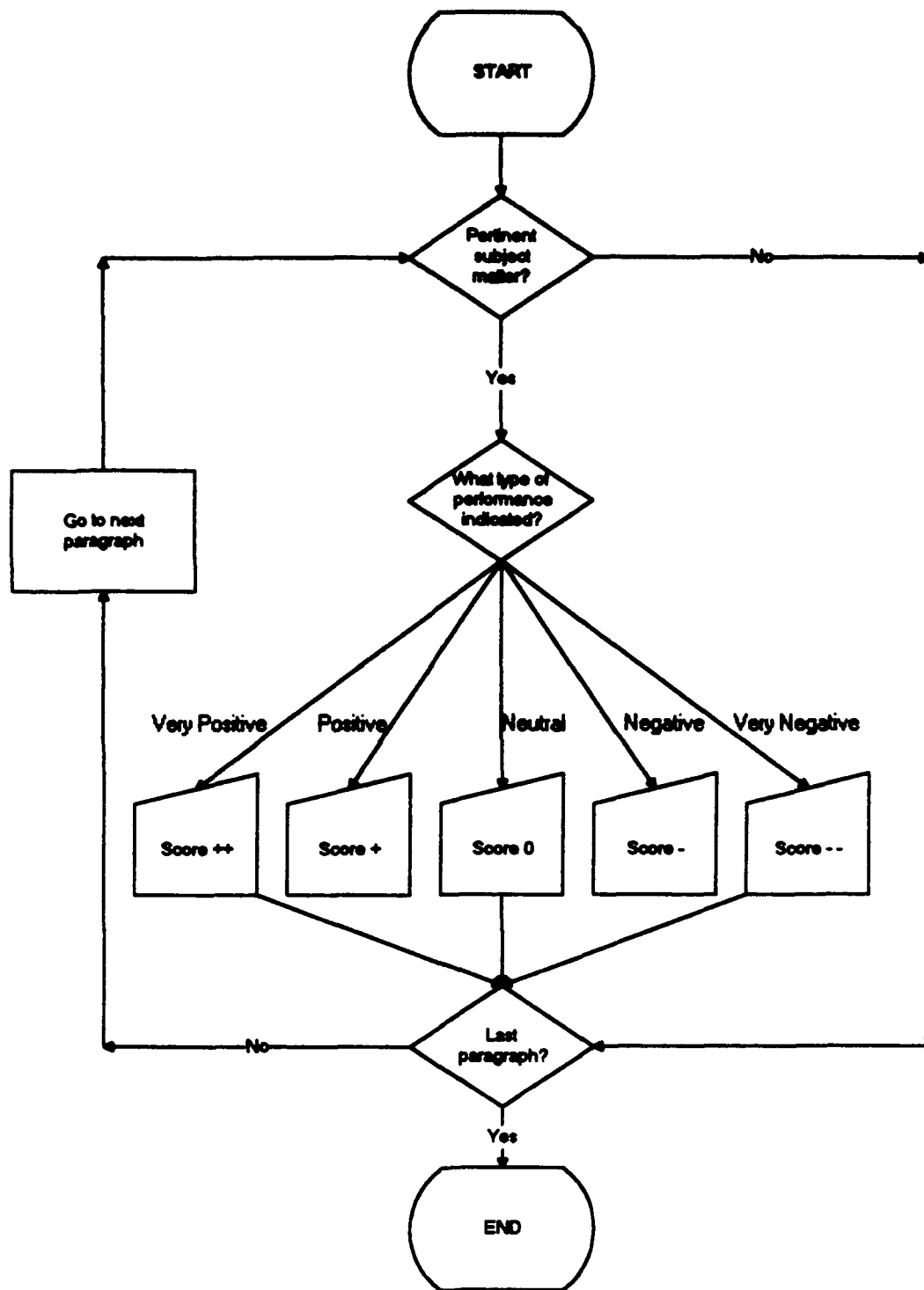
5. Consider the relative time of the events being discussed in the narrative. Some have more impact than others.

(i.e. early tracking of enemy recon elements is almost certainly more important to this analysis than events that occurred in the counter attack.)

6. I realize that many paragraphs are not well written, and many are nothing more than stand alone sentences. Feel free to group them as you wish and score them collectively. I just ask that you draw arrows and braces so I know how you scored them.

7. Beware of *preaching* that can occur from the author of the THP narrative.

8. Note that the second portion of the THP narrative is consolidated comments from the entire rotation, NOT just the defense-in-sector mission segment.



## APPENDIX D

### SAMPLE SCORING OF THP NARRATIVE

A sample battle THP narrative is shown here with the scores displayed in the text box to the right of each paragraph. There are two scored sections in each of the THPs. Any key statements within the sentence are shown in bold typeface. The first section comments on the BOSSs, and the second discusses performance trends. Any references to the rotation number or unit designation have been removed or disguised.

#### INTELLIGENCE OPERATING SYSTEMS

##### 1. MISSION: DEFENSE IN SECTOR

DATE: DD MMM YY

##### a. SUMMARY OF EXECUTION

##### (1) THE S2

**The staff synchronization by the battalion staff improved in regards to the development of the DST.** The S2 still was not given adequate time to prepare IPB for the planning staff and was forced to provide cursory support. **He was able to fully develop the basic IPB products in time for distribution during the OPORD.** The staff developed a fairly complete DST, yet due to heavy attrition of the command and control elements at the preliminary stages of the battle, the identified decisions were not executed. **The template developed by the S2 did an excellent job of identifying MCs and avenues of approach,** with the exception of two dismounted routes in the southern AOs, and through the area known as John Wayne Pass, by which the OPFOR actually conducted dismounted operations. **Timelining the advancing enemy by the S2 was fairly accurate, with little error.**

Paragraph  
Score: +

**The counter-reconnaissance plan developed by the S2 and S3 lacked the necessary synchronization to make it effective. This coordination also involves ensuring that all elements execute their tasks and are sufficiently resourced to conduct their mission, to include having adequate and operational night sights, operational radios, and graphics. Timely execution of assigned tasks are also critical, especially when it comes to a counter-reconnaissance mission. When all of these shortfalls were combined (i.e., scouts executing security screen late and without proper night vision capabilities, and inadequate handoff between tracking and destruction assets), you will repeatedly have what occurred, successful penetration of the AO by enemy reconnaissance.**

**Paragraph  
Score: -**

**The S2 was able to maintain a timely track of the counter- recon battle and made an estimate of the probable COAs by the enemy based upon the known reconnaissance effort. He also was able to maintain an accurate assessment of what elements had been destroyed and what remained. The TOC was destroyed during the early phase of the battle by enemy reconnaissance elements and the S2's track of the main battle ended prior to the enemy actually entering the task force's AO. Other intelligence concerns observed during the operation included the use of proper radio techniques on unsecure radio nets and establishment of local security for the TOC, both which dealt with OPSEC and counter-intelligence operations.**

**Paragraph  
Score: ++**

## **(2) SCOUT PLATOON**

### **(a) MISSION SUMMARY**



The scout platoon was to occupy a stationary screen forward of the task force during a defense in sector.

Paragraph  
Score: 0

**(b) PLAN**

The platoon was to occupy three scout OPs, two on Furlong Ridge and one in the John Wayne Hills, with GSR and LRP teams attached. The platoon was to conduct the operation during both night counter-recon operations and during the regimental main attack.

Paragraph  
Score: 0

**(c) PREPARE/EXECUTE**

The platoons preparation prior to each mission has continued to improve, particularly in the area of PCC/PCI, weapon test fire, and OP/ patrol preparation; however, the platoon has yet to conduct any leader recon or rehearsals in conjunction with the OPORDs.

Paragraph  
Score: 0

The platoon did not occupy its screen until 040900 Mar 89; consequently, they did not participate in the first night counter-recon operation during the DRT insertion. The platoon's ability to detect the OPFOR recon on 5 Mar 89 was severely limited due to the lack of thermal devices (none on hand). During the mission, the platoon was unable to track the regiment because it was attrited by friendly artillery, NBC, and OPFOR dismounts.

Paragraph  
Score: -

**INTELLIGENCE TRENDS**

**1. PERFORMANCE TRENDS:**

Observations of Task Force 3-70, Armor's, intel operations covered the areas of planning, preparation, and execution of missions, administrative operations and recon/counter-recon planning and execution.

Paragraph  
Score: 0

**The DST generally was developed after the formal planning session (war-gaming process) and was merely a reflection of the plan. This did not allow the staff to confirm or deny the capabilities and/or limitations of their assets to execute the plan and thus reduce the changes which might be made prior to production and distribution of the DST. Staff interaction by the S2 started out at an acceptable level. At the end of the training period, levels of coordination and synchronization between the S2 and the FSO, the staff engineer and the ALO as well as ADA officer had improved, especially in the development of the situation template. Adjacent unit coordination was generally affected either by radio or by on the ground coordination at brigade, but this did not occur every mission. Consequently, the S2 did not always have knowledge of the adjacent units recon/counter-recon effort until his own plan had been finalized. The most serious problem observed involving the S2 in the planning process was the commander allowing him sufficient time to develop a preliminary IPB product to support the planning process. He frequently had to brief from the brigade product without the opportunity to refine the product for the task force's specific AO.**

**Paragraph  
Score: -**

**The S2 was always abreast of the status of the recon/counter-recon effort, his situation template was up-to-date and he continually studied and analyzed his SITMAP for new observations and analysis to disseminate.**

**Paragraph  
Score: ++**

**Observations of intel operations during the execution phase of the mission involved the tracking of the battle in terms of friendly and enemy activities, analysis, and dissemination of SPOTREPs (to and from higher**

headquarters). The attempts to track the battle were progressive; however, available information did not always enhance the process and ultimately reduced the S2's ability to quickly analyze and evaluate the situation in reference to those COAs available to the OPFOR. Improving the quantity and quality of spot reporting, to include enemy BDA, would have greatly enhanced his efforts to conduct analysis.

Paragraph  
Score: 0

Recon and counter-recon operations were generally, but not always, executed in a timely manner. Planning for the missions always occurred early to allow the elements executing the plan more time for planning internally and for execution. Heavy reliance was placed upon establishing OPs for collection of information, and the scouts were seldom given route, zone, or area recon missions. When the scouts were given a mobile mission, it usually involved screening the task force's flank. OPs were generally limited in collection capabilities by communications equipment and visibility conditions, which can be affected by weather, terrain, or smoke operations. Survivability of OPs was limited by mobility and enemy direction finding efforts during the reporting process. Overall, recon plans were generally executed successfully, but frequently failed to provide sufficient information for analysis.

Paragraph  
Score: +

Finally, administrative operations during the training period were commendable. The journal improved and became a valuable tool in the tracking process. The SITMAP was constantly updated to show the latest intel. Operations maximized the use of resources and personnel. Graphics and annexes for the OPORD were always ready for distribution during the OPORD.

Paragraph  
Score: ++

**Operations security needs emphasis and improvement across the task force. Light discipline, radio procedures and garbage and sanitation control all need improvement to ensure that the operational status of the task force is not compromised.**

**Paragraph  
Score: -**

### **Score Tally**

**Total "++" paragraphs:  $3 \times 3 = 9$**

**Total "+" paragraphs:  $2 \times 1 = 2$**

**Total "0" paragraphs:  $5 \times 0 = 0$**

**Total "-" paragraphs:  $3 \times (-1) = -3$**

**Total "- -" paragraphs:  $0 \times (-3) = 0$**

**Score for battle:  $9 + 2 - 3 = 8$**

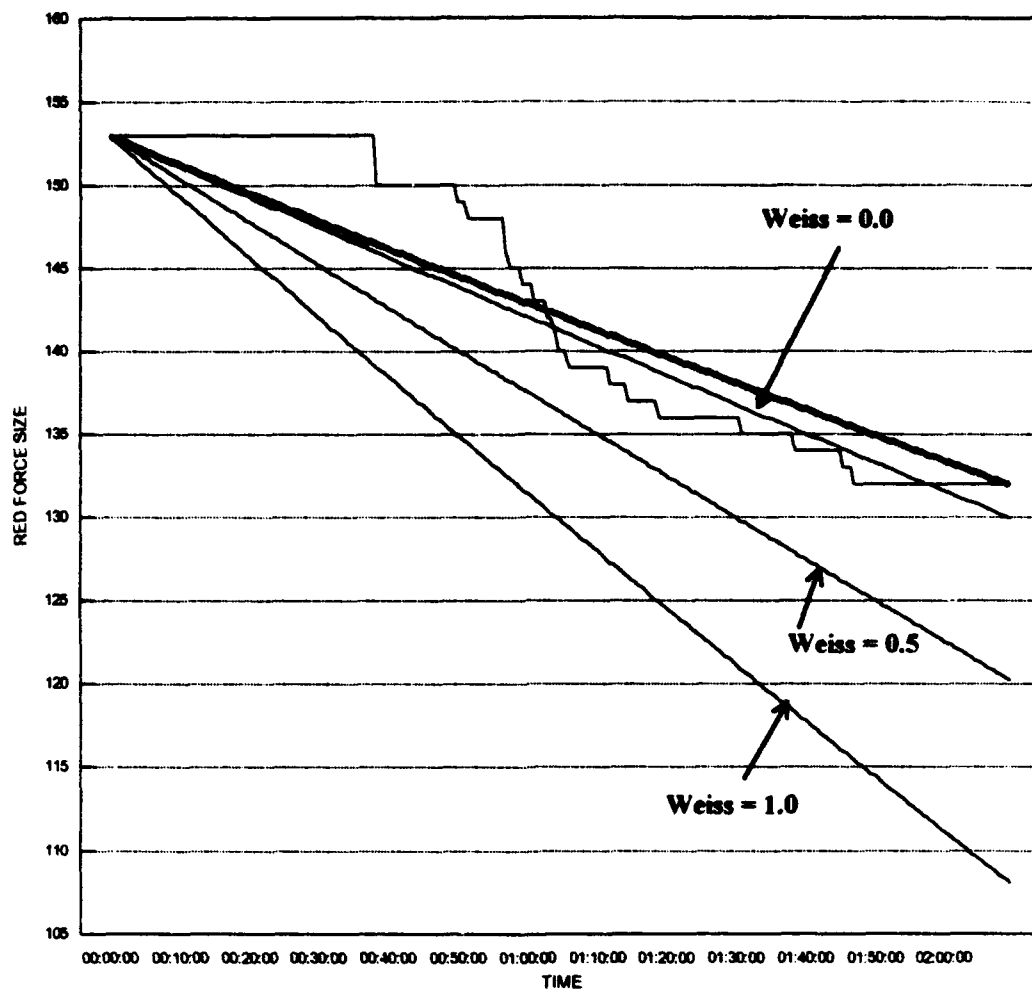
## **APPENDIX E**

### **COMPARISON OF MODEL WITH ACTUAL BATTLE DATA**

This appendix contains graphs for each of the ten NTC battles, which compare the COMAN maximum likelihood estimate of red's attrition rate to the modified Helmbold equation with the Weiss parameter set at 0.0, 0.5, and 1.0. A plot of the actual red force size for each battle is also included.

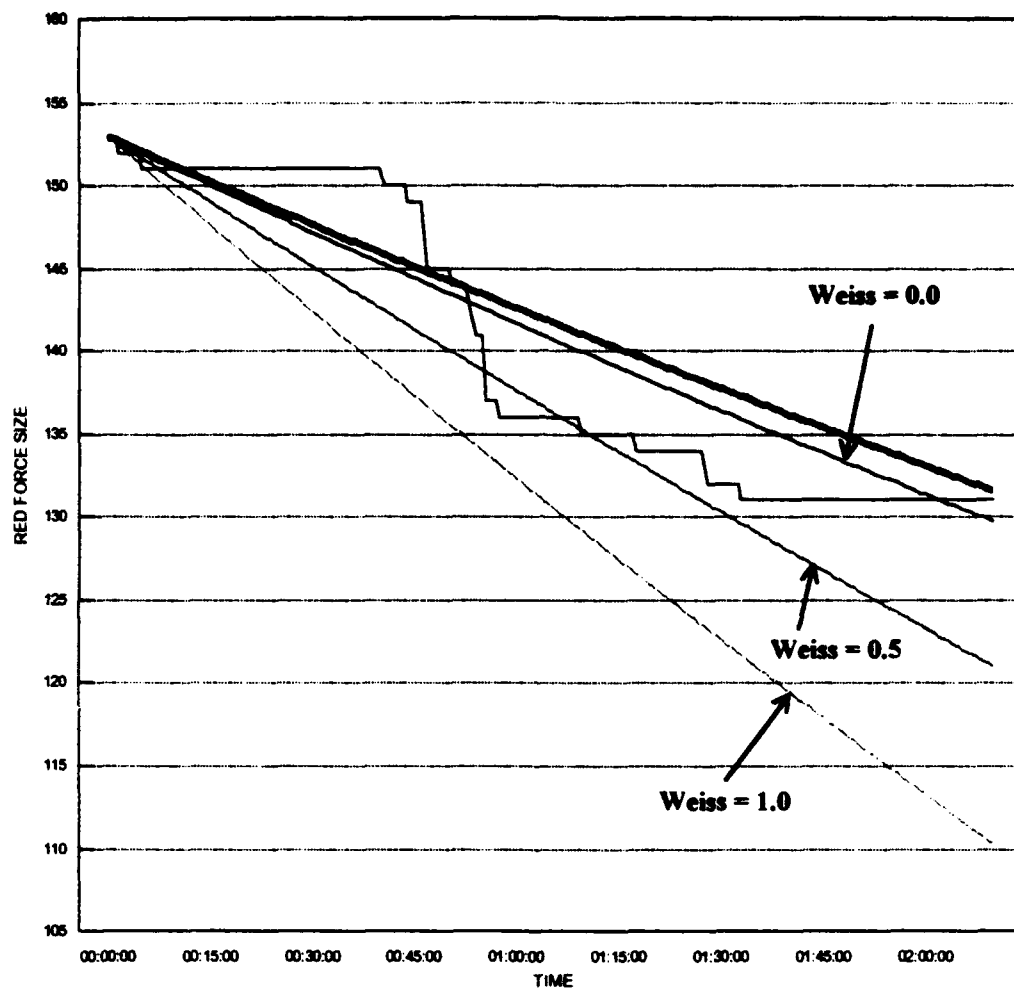
# Comparison of Model with Actual Battle Data

Battle #1



-- Actual Data      = COMAN MLE same as Weiss = -0.12

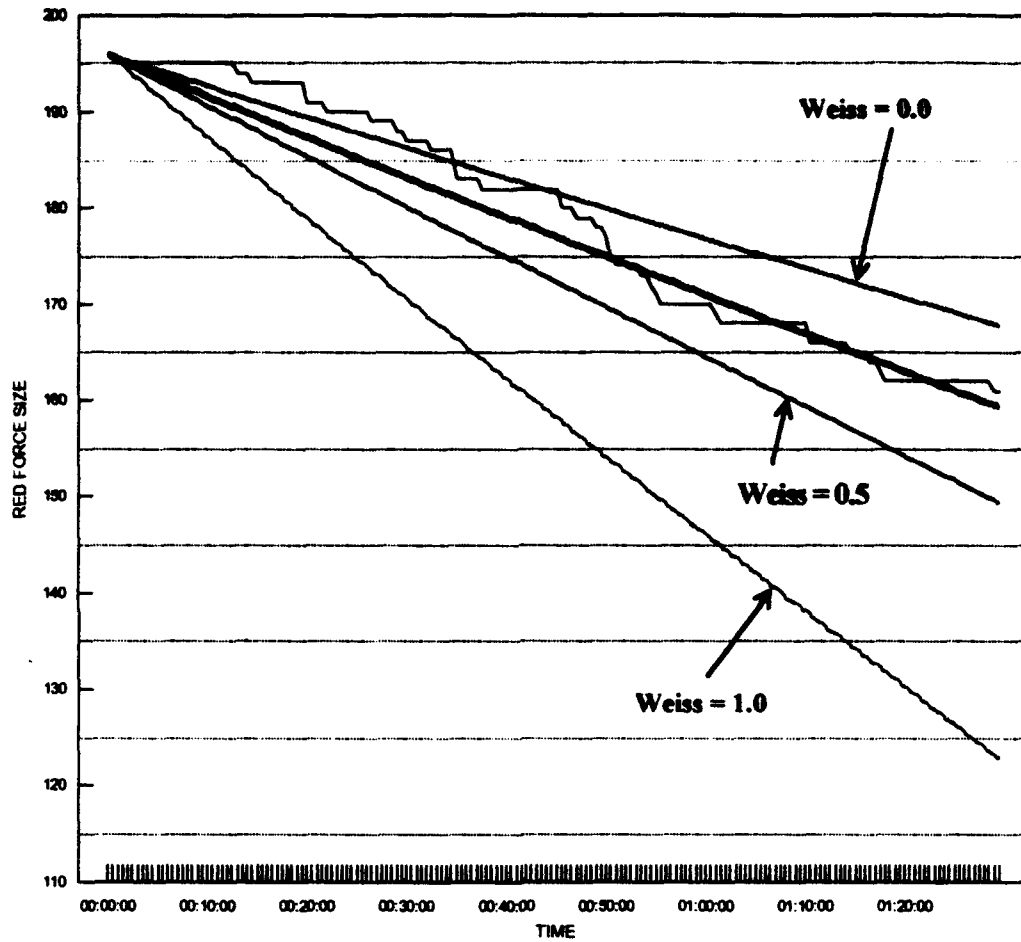
# Comparison of Model with Actual Battle Data Battle #2



— Actual Data      • COMAN MLE same as Weiss = -0.13

# Comparison of Model with Actual Battle Data

Battle #3



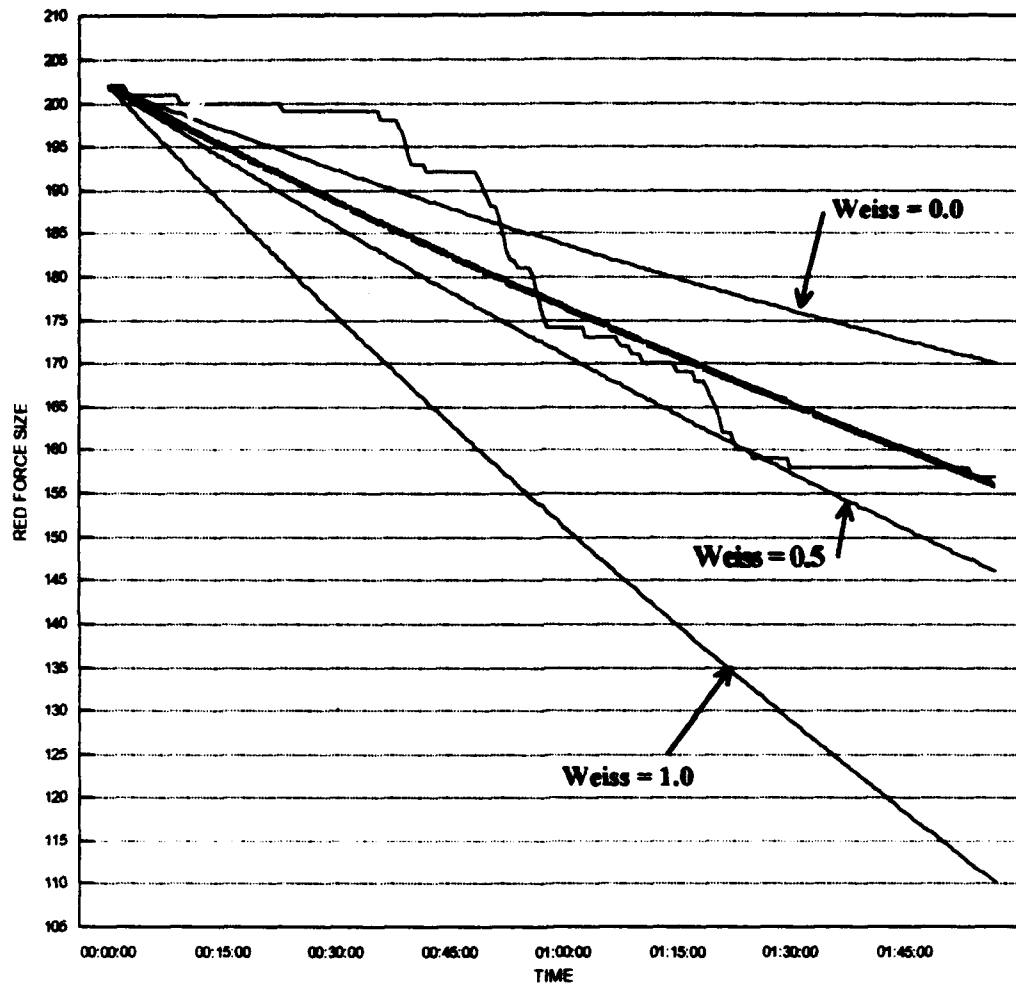
— Actual Data

— COMAN MLE same as Weiss = 0.27



# Comparison of Model with Actual Battle Data

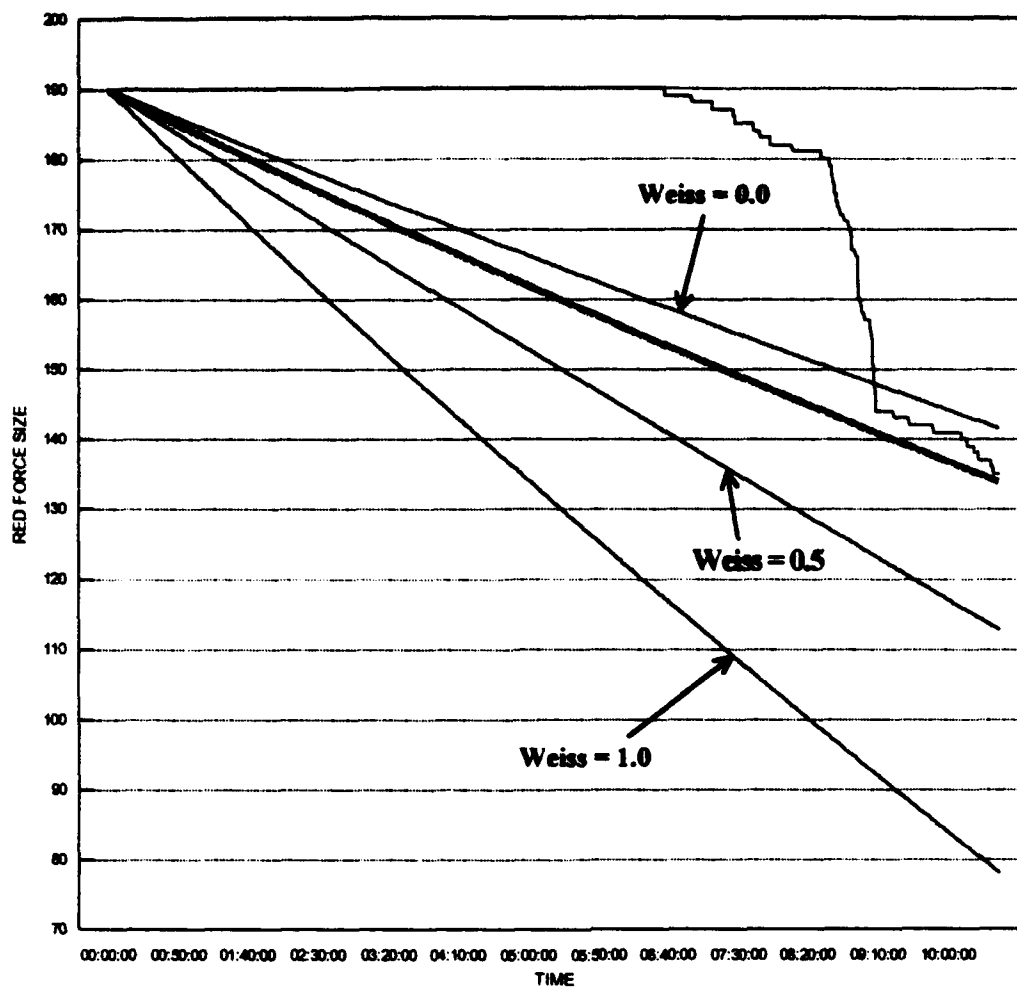
Battle 24



- Actual Data      = COMAN MLE same as Weiss = 0.31

# Comparison of Model with Actual Battle Data

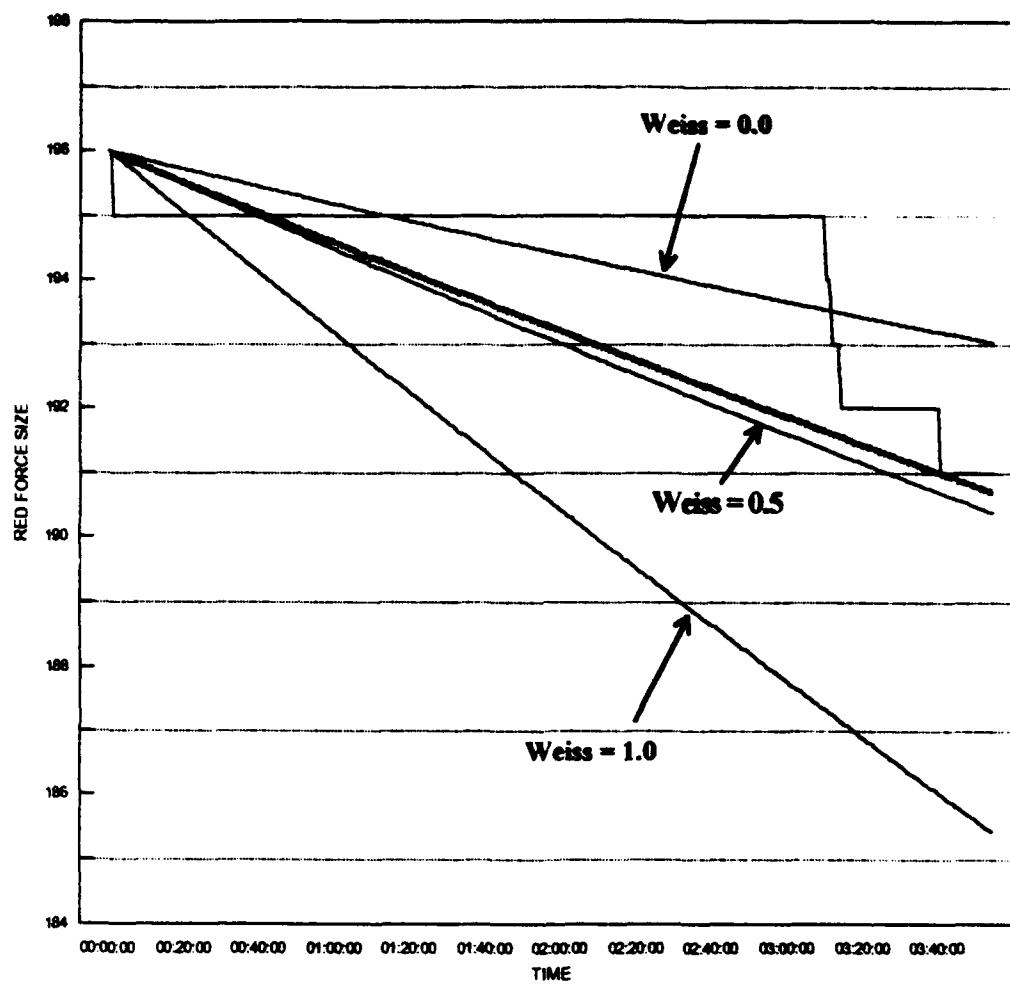
Battle #5



— Red Actual

— COMAN MLE same as Weiss = 0.16

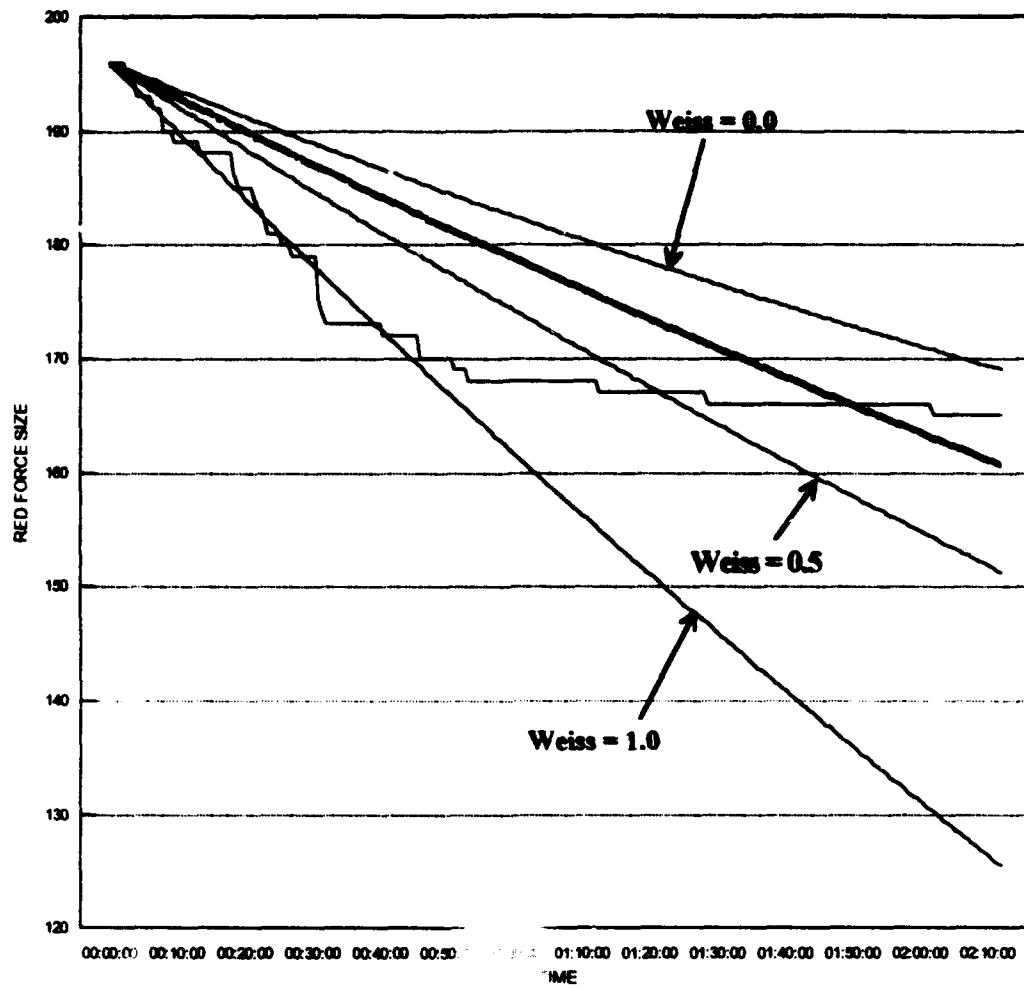
# Comparison of Model with Actual Battle Data Battle #6



- Red Actual      = COMAN MLE same as Weiss = 0.45

# Comparison of Model with Actual Battle Data

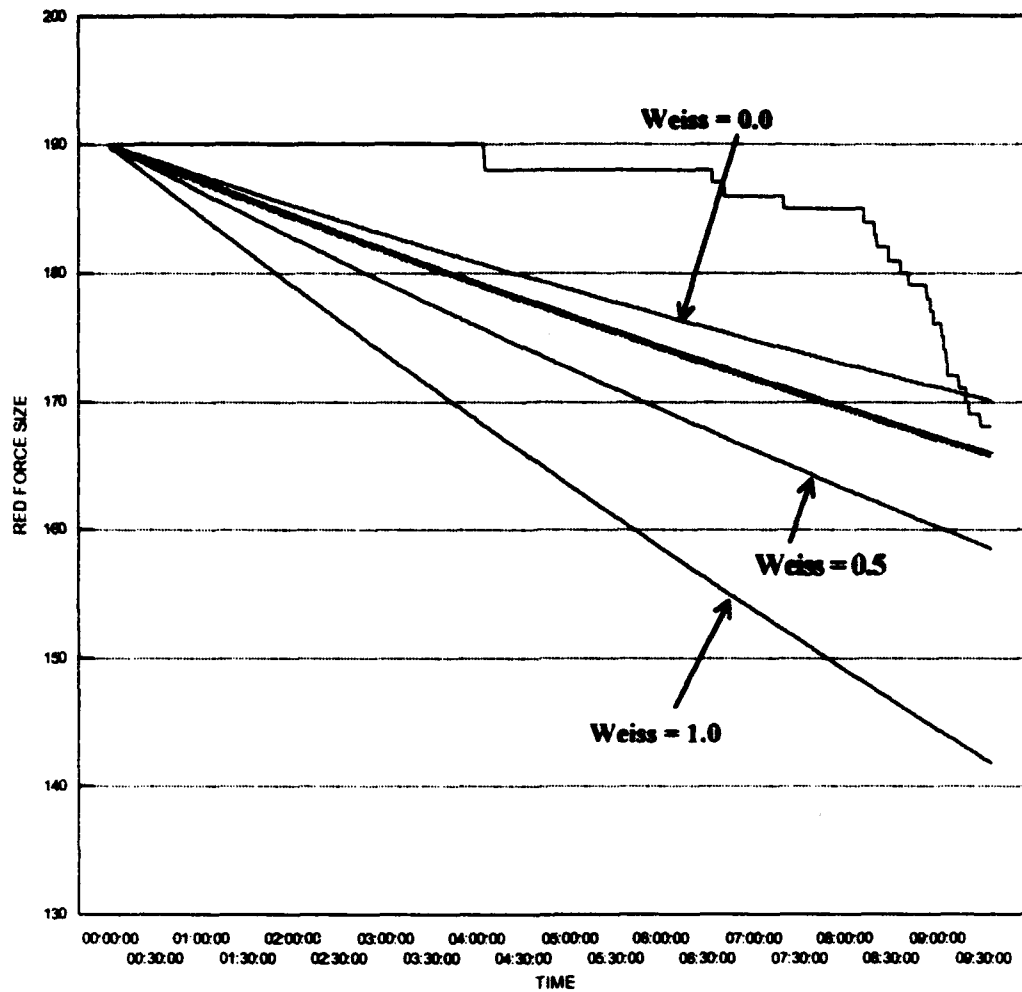
Battle 87



- Red Actual      = COMAN MLE same as Weiss = 0.25

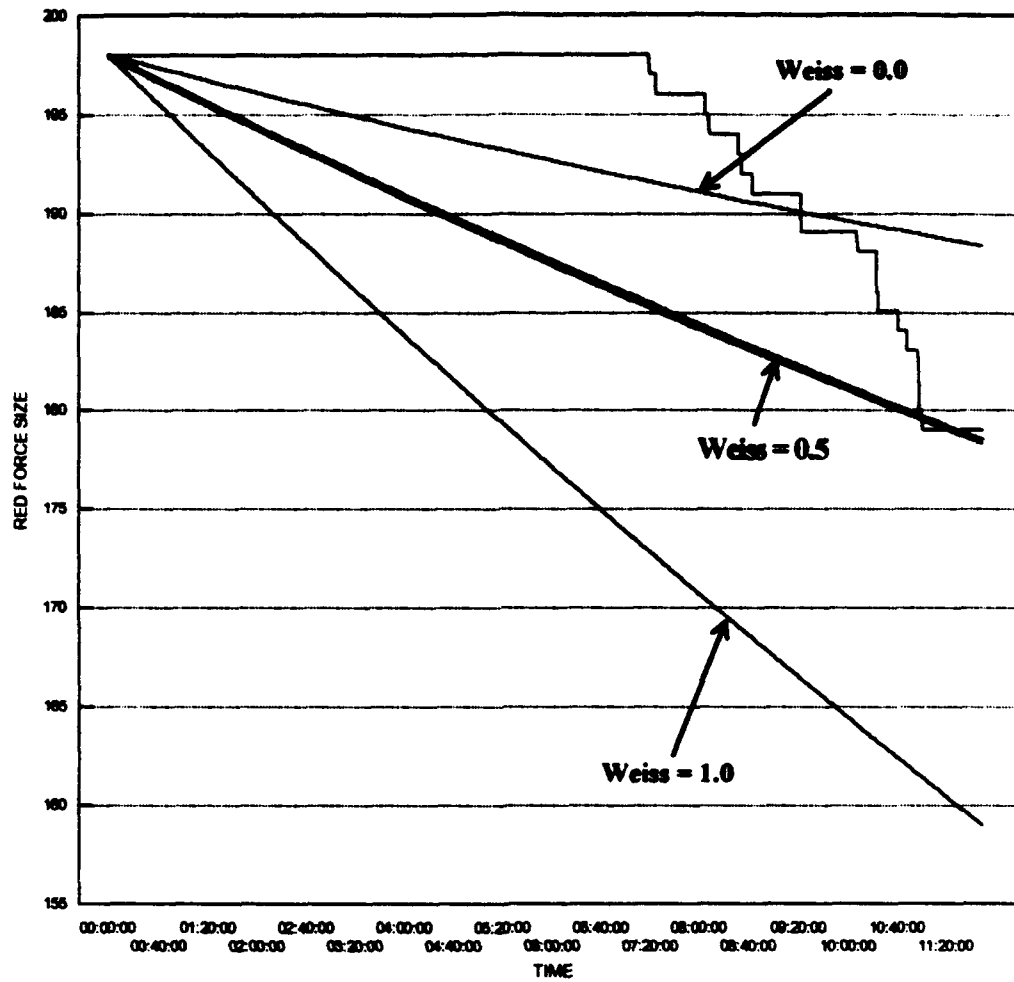
# Comparison of Model with Actual Battle Data

Battle #8



# Comparison of Model with Actual Battle Data

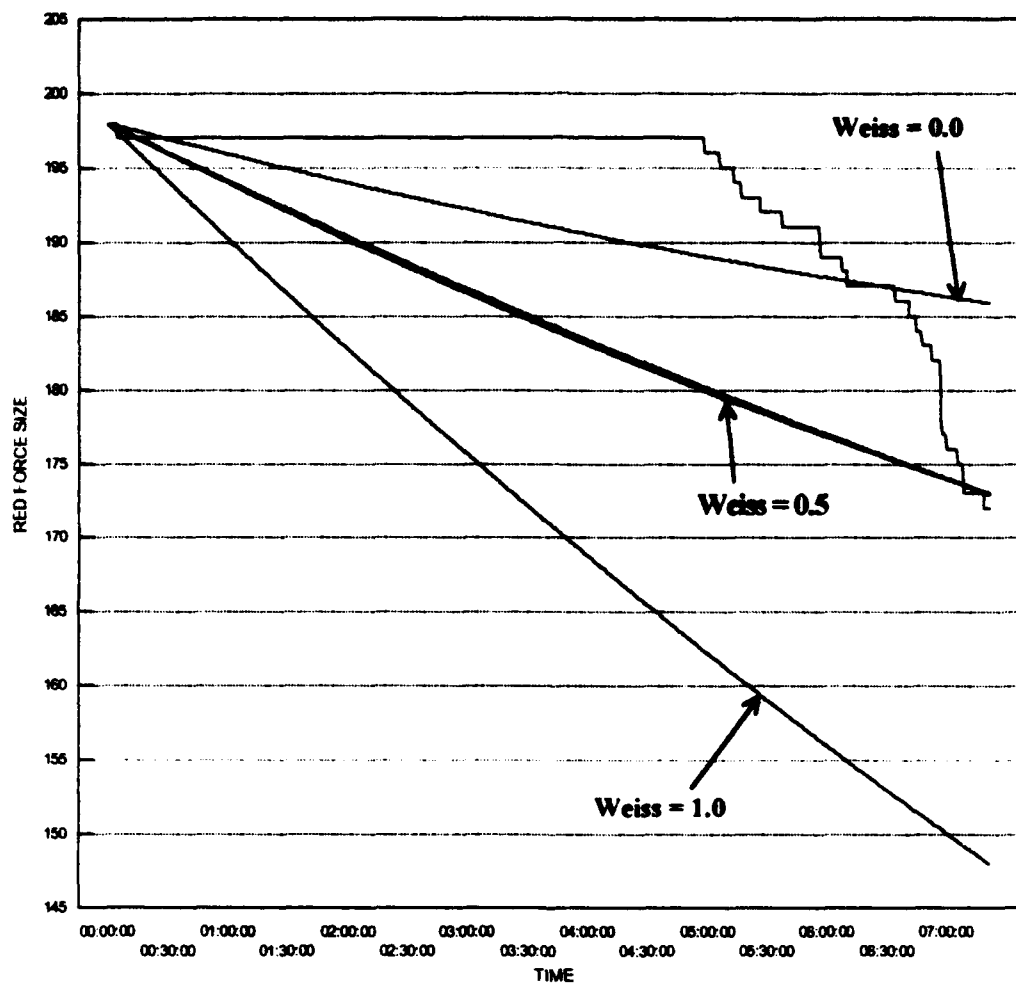
Battle 88



— Red Actual      — COMAN MLE same as Weiss = 0.49

# Comparison of Model with Actual Battle Data

Battle #10



- Red Actual      - COMAN MLE same as Weiss = 0.50

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